

# **Collaborative Small Groups in Physics Courses**

**With a case study from PHYS102 at  
the Department of Physics and  
Astronomy 1998**

***Derek Chirnside***

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As a teacher who has stumbled across the world of Education Research somewhat late in life, I have felt, at times, like an alcoholic in a pub, or, to change the metaphor, like I was surrounded by an ocean of knowledge and having a teaspoon. Thanks are due to my co-supervisor Professor Philip Butler, for his support and encouragement over four years as I have worked part time on papers towards an MScEd. He has made sure that I have remained living in the real world. The course he and John Longbottom taught in 1996, EDUC678, *Issues in Science Education*, began what was a major revolution in my approach to science teaching.

I have also appreciated the help of Professor Graham Nuthall in navigating my way through the labyrinth of Education journals, research papers and the world therein while a part of his EDUC644 course *Research on Teaching*. He has also been my co-supervisor for this dissertation.

I believe that there is significant benefit from combining insights from the disciplines of science and educational research in the light of practical teaching experience in the classroom, laboratory and lecture theatre.

In what follows I report extracts from a number of recorded conversations with students in the 1998 class of PHYS102 at the Department of Physics and Astronomy. I am grateful to these individuals for letting me look into the fascinating and complex world that is their view of physics and physics classes.

Also, thanks to my wife Phillipa and my family who have put up with my absence for many late nights, some weeks of holidays, and frequent periods of preoccupation, even when I was physically with them.

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## Abstract

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A constructivist model for physics instruction is developed adapting ideas from recent overseas work in physics educational research. Based on this model, small group collaborative problem solving activities were introduced into PHYS102 tutorials at the Department of Physics and Astronomy at the University of Canterbury in 1998. Students were given a prescribed problem solving strategy, and a formal process for groupwork. Observations and data gathered from recordings of students working in small groups were used to evaluate these changes. Well functioning collaborative groups were found to assist in developing concepts and understanding, particularly through student discussion that has been called 'second teaching', an idea which is interpreted using theory from Lev Vygotsky. Collaborative problem solving with well-functioning small groups can often produce better quality solutions than from individuals on their own. The role of 'monitor' or 'critic' was found to be essential for high-performing groups. Such groups do not happen automatically, and the role of tutors in helping establish and manage a collaborative environment is crucial. Student feedback, gained from questionnaires and follow-up interviews, was positive. There are differences between the culture of this country and that of overseas where the original research was conducted. This has lead to recommendations that for implementing groupwork in this country, tutor training be improved, and that each tutor group be involved initially in refining and adapting a shared understanding of group work and problem solving.

# 1. Introduction

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In the last two decades there has been much debate about improving introductory undergraduate physics courses. For example, see Hestenes (1987), Halloun and Hestenes (1985), Heller and Hollabaugh (1992a), Heller et al (1992b), Van Heuvelen (1991), Trowbridge and McDermott (1981). In much of the English speaking world, such first year courses have been based around a series of three components: lectures, laboratory work and tutorials. In the American context, the term 'recitation' is a close equivalent of the New Zealand 'tutorial'. Various reform movements have sought to bring changes to the teaching methodology in these courses.

A wide-ranging summary from an American point of view is contained in Redish (1996a). Linder and Hillhouse (1996) report on a significant study at the University of the Western Cape, South Africa. Welzel and v. Aufschnaiter (1997) from the Institute of Physics Education at the University of Bremen write on a range of studies from a European perspective. What is common to these, and a large number of further research projects, is a cautiously optimistic view that real progress is occurring in improving the results of students studying introductory physics.

The focus of this dissertation is change in the nature and purpose of the tutorial component of introductory physics courses. The studies quoted above report good results in of South Africa, America and Europe. The question for us was: "What do these approaches have to offer physics courses in New Zealand?"

Traditionally, tutorials have been tutor-centred and students have worked individually. For many students the results have been poor (Halloun and Hestenes, 1985; Gatreau and Novemsky, 1997; Linder and Hillhouse, 1996). Recent new understandings of cognitive development theory by some sections of the physics teaching community has led to a variety of different approaches to tutorial work. Chapter Two of this dissertation presents in broad terms a theoretical overview of cognitive development theory as it is relevant to physics education. This is largely based on the foundational work of Lev Vygotsky and Jean Piaget.

The community of workers in physics educational research have freely adapted and modified these ideas from cognitive development theory to form a model for learning in physics. While this model has the label 'constructivist' by physics educators, it does incorporate other themes in cognitive theory as well. Chapter Three describes a version of this model. With this as a basis, changes have been implemented in the approach to tutorials in many introductory physics courses. The results of these reforms have been encouraging.

For example, Gatreau and Novemsky (1997) at the New Jersey Institute of Technology have reported large gains in student understanding following tutorial work in structured small group settings. Their work was based on OCS (Overview, Case Study) Physics as developed by Alan Van Heuvelen (1991). Linder and Hillhouse (1996) have reported similar results at the University of Capetown. Their research indicated that not only

were gains greater in the structured small group tutorial settings, but retention and understanding was much longer lasting.

David Hestenes at Arizona State University, has worked on another programme, based around a structured modelling approach (see for example Hestenes, 1987). As part of this, students work in small groups on interactive, cooperative problems. In various tests, students have made significant gains when compared with traditional methods (Hake, 1998). Studies at the University of Minnesota (Heller, Keith and Anderson, 1992b) have shown that better problem solving skills are developed through collaboration in well-structured small groups.

There are many other programmes which have produced similar positive results, for example, Active Physics (McDermott, 1993a), RealTime Physics (described in Redish, 1994) and Minds on Physics (Leonard, 1998).

In summary, one common factor in these reforms is the introduction of some form of structured small group problem solving activities, based on a moderate constructivist view of learning.

It was decided to implement some changes to tutorials for PHYS103 (Thermal Physics and Electromagnetism) in the second semester of 1997 at the Department of Physics and Astronomy. PHYS103 is the second of two introductory papers in physics. These changes first occurred in tutorials for the second semester in 1997. For the tutorial component of this course, problems were designed which outlined a series of steps towards a solution, and students worked on these in collaborative small groups.

In June of 1997, Professor Philip Butler had a chance to visit and observe first hand Overview Case Study Physics with Ronald Gatreau at New Jersey Institute of Technology and David Hestenes' Modelling approach at Arizona State University. On the basis of these visits and with some positive feedback from the 1997 PHYS103 trials, major changes were planned for tutorials in PHYS102 (Dynamics, Waves and Atoms) in the first semester of 1998.

Chapter Four describes in detail the changed structure and approach to the PHYS102 tutorials. The specific form of these changes was largely based on methodology from the University of Minnesota. For a full account see Heller et al (1992b) and Heller and Hollabaugh, (1992a). There were three key features to the way they have redesigned their tutorials in Minnesota: the use of a new type of problem, carefully structured group work and the teaching of an explicit problem solving strategy.

This dissertation reports on some exploratory research into the effect of these changes to PHYS102. Chapter Five outlines the methodology of this research. There were two main sources of data. Firstly, to gain student feedback, eleven students completed general questionnaires on matters relating to the tutorials. These were used as the basis for a recorded interview with each student. Chapter Six and Seven contain a presentation and analysis of the students responses. Secondly, to gain some insight into the working of the groups, seven small group problem solving sessions were recorded.

A detailed account of one of these is contained in Chapter Eight with data and observation from other recorded sessions in Chapter Nine.

Chapter Ten reports on feedback from tutors and contains a comparison of examination results from the previous year. Chapter Eleven contains a summary of findings from this exploratory study. The new style tutorials were generally well received by students, and the evidence suggests that the collaborative small group environment is beneficial to students' learning.

## 2. Theoretical Underpinnings from Cognitive Development Theory: Lev Vygotsky and Jean Piaget

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### 2.1 Introduction: The Socio-cultural view and Constructivism

A large number of studies into the effectiveness or otherwise of collaborative small groups, has been carried out over the last thirty years. David and Roger Johnson carry out a survey and summary of the research every two or so years. They now report over three hundred studies in the field at University level (Johnson, Johnson and Smith, 1998a). The theoretical basis for collaborative learning now includes some ideas from cognitive development theory. Two significant perspectives represent the poles of a spectrum of views. The first of these is the *constructivist* view generally acknowledged as being based on the work of Jean Piaget. In seeking to explain how learning takes place, this view focuses on the individual and what is going on inside the mind of that individual. Some other writers refer to this as *psychological constructivism*, for example, Cobb and Yackel (1996). Dillenbourg et al (1996) use the term *socio-constructivism* to refer to the way the view has been developed from Piaget's original ideas. The second perspective is the *socio-cultural* view. This is based on the writings of Lev Vygotsky, a Russian psychologist and philosopher who worked during the 1920s. He emphasised cultural and social contexts for learning where the community or group context plays a central and crucial role in learning.

A Piagetian approach sees social interaction as merely providing a catalyst for individual change. This change is generally internal and dependent on individual development. On the other hand the Vygotskian perspective sees the interpersonal interactions as *primary*, and are themselves being internalised by the individual. Vygotsky's primary focus is on the social interaction of the group whereas Piaget's focus is on the individual.

This is a slight overstatement of the distinctions between these two views. Piaget did not deny the significant role in the social world in the construction of knowledge:

.. there is no longer any need to choose between the primacy of the social or that of the intellect: collective intellect is the social equilibrium resulting from the interplay of the operations that enter into all co-operation. (Piaget, 1970, p114)

There are other quotations, especially in his later writings, which support a view to suggest the social and group context is important in his thinking. Vygotsky himself quotes Piaget:

. . when one works, as I do, with one and the same social milieu in Geneva, one is unable to give relative weights to the social and individual contributions in the development of a child's thought. In order to achieve this goal one should be able to study children in the most varied and contrasting social milieu. (Quoted in Vygotsky, 1986, p56)



Also in Vygotsky's work there are strong indications that show he has an interest in the events occurring *in* the mind of the student. He has written extensively on the development of higher mental functions. (For example, Vygotsky, 1997) He also has a strong focus on speaking and its role in the development of thinking and other 'intra-mental functions'. (See for example Vygotsky 1978 Chapter 4 Internalisation of Higher Physiological Functions) These actions are very much an individual thing. Yet he never wavers from a view that the *group interaction* is primary and precedes real learning in the individual.

## **2.2 Some historical background**

It is not my intention to develop the genesis of the work of Piaget and Vygotsky in detail. However some brief historical background which focuses on their influence on the English speaking world may be useful.

Joseph Glick in the preface to Vygotsky (1997) has presented an account of the interplay between the work of Piaget and that of Vygotsky. According to Glick, Piaget's work was seen as an answer to constraints imposed by the previously dominant *behaviourist* view. A stream of books during the 1960's presented a Piagetian-oriented developmental psychology. Many aspects of this, however, were an interpretation of the Piagetian theory as received by the English-speaking establishment. As such, it began to come under pressure from a number of directions, including questioning of Piaget's account of the developmental process and the limiting aspects of a view which saw future development constrained by initial conditions. Vygotsky's first book *Thought and Language* (1962) contained seeds of a new direction. But it was not until his ideas were reintroduced to the English-speaking world with the publication of *Mind in Society* in 1978 that his theories began to spark intense interest.

Glick comments:

This publication came at the point of disenchantment with the Piagetian treatment of structure – and hence seemed to be an answer to the problems encountered over a two-decade involvement with Piaget. (Prologue to Vygotsky, 1997, page ix)

It is acknowledged that there has been an interpretation of the work of both Piaget and Vygotsky by the English speaking community. This is partly due to the issues of translation. Also, major details involving the significant concept of the *zone of proximal development* in Vygotsky's book first translated in 1962 *Thought and Language* were greatly expanded in the second major work published in translation *Mind in Society* which appeared in 1978. There is a long time lag between Vygotsky's original work in the 1930's and its publication in English. Furthermore, a second edition and retranslation of *Thought and Language* which was published in 1986 also introduced variations of Vygotsky's ideas. These subtleties aside, Vygotsky's key ideas in their translated and interpreted form, have come to have a significant influence on the present commonly held views.

### 2.3 Two Other Views: Behaviourism and Distributed Cognition

A further comment by Glick mentions *behaviourism*:

. . . though Vygotsky might look like a behaviourist at first glance, he wasn't really one.  
(Glick, 1997, page ix)

Behavioural learning theory is also given special mention by Johnson et al (1998a) in their analysis of cooperative learning as one of the other critical theoretical foundations in support of cooperative learning. It assumes that students will work hard on tasks for which they will gain reward, and will fail to work on tasks that yield no reward or yield punishment. However behaviourism tends to focus only on what is directly observable and in this respect has been found wanting.

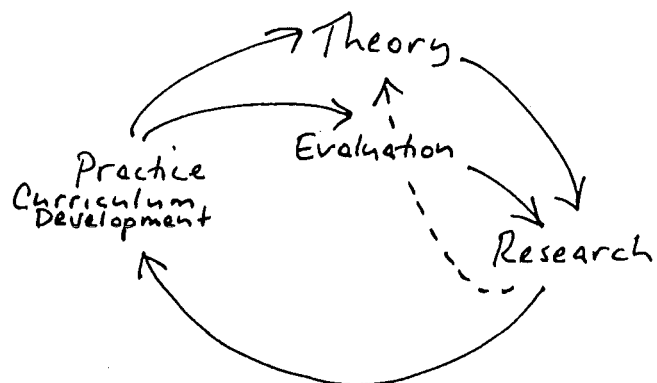
In his analysis of the research basis for collaborative learning, Dillenbourg et al (1996) lists *distributed cognition* alongside the socio-cultural and socio-constructivist theories as a significant influence in collaborative learning research. This theoretical position has received a lot of attention over the last decade in research and theoretical works, but as yet has received little response from the field of physics education research. One possible exception is research associated with the Institute of Physics Education at the University of Bremen and a number of other European studies (Welzel and v. Aufschnaiter, 1997). However, an examination of some of the descriptive terms used in these studies leads to the conclusion that their thinking is not too far removed from a modified socio-cultural perspective.

### 2.4 Theory and Evidence

The detail and interpretation of socio-cultural theory is slowly changing and developing as further research has been carried out. (See for example Wells, 1994) Theory, research and practice are intimately related. As behaviourism has given way to cognitive theories, and these in turn have been challenged by socio-cultural theory, there has been a new focus for research. In the light of new theoretical developments, further studies have been carried out. These studies in turn have enabled refinements in practice and further new theoretical speculation.

For example, Gordon Wells at the Ontario Institute for Studies in Education, Toronto, lists a large number of recent studies in Wells (1994; 1996). He works with local teachers in an

effort to develop improved skills and methodology. The findings in his work with teachers in turn feeds back into research activities. There are other initiatives like this, often associated with a teacher training institution or university research group.



The Links between Theory, Research and Educational Practice

This shows the intimate link between theory and evidence. It is difficult to make observations to develop or seek confirmation for theoretical ideas without first having a theoretical basis to proceed from. Assume for example, that an observer's prior theory is biased towards an individualistic locus for development. This bias may cause genuine data of significance to another point of view to be unintentionally screened out.

As the research basis for collaborative learning and its interpretation has matured, attention has been brought to bear on some of the more subtle factors involved. The mere examination of different types of tasks in a research project can lead to a different perspective. Dillenbourg et al (1996) comments:

Tasks that have been typically used in collaborative learning from a Vygotskian perspective include skill acquisition, joint planning, categorisation and memory tasks. In contrast, the implication from socio-cognitive theory is that tasks should promote differences in perspectives or solutions. Typically, conservation and co-ordination tasks involve perspective-taking, planning and problem solving. There is thus little overlap in the nature of tasks investigated from the Piagetian and Vygotskian perspective. It is also clear that the nature of the task influences the results: one cannot observe conceptual change if the task is purely procedural and does not involve much understanding; reciprocally one cannot observe an improvement of regulation skills if the task requires no planning.

*Where* an observer looks can influence the conclusions drawn. The types of tasks examined can influence the conclusions reached, whether knowledge is individual or social in origin. Piaget's focus was on perspectives and restructuring concepts often imposing structural constraints and sharp limits on learning. Vygotsky emphasised acquiring understanding and skills and tended to emphasise open possibilities.

This theory dependence of observation is an important issue. In the early stages of theory development researchers tend to look where the (theoretical) light is brightest and more subtle issues can get left until later. Also, new tools can be developed to improve observational capacity. Many subtleties in classroom interactions have only been easily observable in recent decades with the advent of video technology. Johnson et al (1998a) point out the important links between theory, research and practice in this way:

Theory is to practice what soil is to plants. If the soil is appropriate and the conditions are right, the plant will grow and flourish. If the theory is valid and the conditions for effective implementation are identified, practical procedures develop and continuously improve. Without an appropriate theory, practice becomes static and stagnant. (p28)

Nuthall (1996) also makes this point.

So long as we hold simplified conceptions of classrooms we will be satisfied with naïve theories of classroom learning and will carry out narrowly conceived research studies. For example if classrooms are seen as places where teachers talk and students listen and learn what they hear, simple behavioural theories can explain that learning. (p208)

Research and theory should reflect as comprehensively and accurately as possible the nature of the thing being studied. (p209)

In other words the *context* of research and the development of theory is extremely important. It is the contexts, the educational and practical settings, that have provided the challenge to research, which has in turn led to fresh theoretical developments.

## **2.5 An Emergent View**

In spite of the differences that have been emphasised above, there is evidence that the way ahead will involve elements of both perspectives. Cobb and Yackel (1996) present a view that points to a *synthesis* of a socio-cultural and a socio-constructivist position. These two perspectives are not yet unified. At present they are more like different facets of the same diamond.

The impetus for the development of collaborative learning methods did not come from cognitive theory, but as time has passed collaborative learning proponents have embraced cognitive theory as a theoretical justification for collaborative learning approaches.

A shift in the language has taken place and ‘cognitive development’ is now often referred to as *conceptual development*. This term is preferable as it does give more recognition of an outside world of ‘real’ concepts, real in the sense that they have acquired shared meaning and do correspond to an outer reality (atoms and their behaviour of matter for example) which does *really* exist. Philosophically speaking, using a constructivist approach to knowledge in no way implies an anti-realist perspective.

In the next section, I present the key tenets of the Vygotsky’s socio-cultural theory and Piaget’s constructivist theory. These have direct relevance to collaborative learning research and a useful model of physics instruction.

## **2.6 Elements of Conceptual Development Theory**

### **2.6.1 Piaget’s ‘Schema’**

In his theoretical formulation Piaget described a process whereby during learning, knowledge accumulates in a student’s mind in mental structures he called “schemas.”

This view of knowledge particularly suits the subject of physics and has been used in some physics education initiatives with useful results in terms of new understanding. Significant examples of this include the work of UMPERG, the University of Massachusetts Physics Education Research Group (Leonard et al, 1994), the model based approach at Arizona State University (Halloun and Hestenes, 1985; Halloun, 1998) and also that of Edward Redish (1994, 1996a). Some productive lines of research in these references consider how schema change and develop, although at times the term ‘mental model’ is used in place of the term ‘schema’.

### **2.6.2 Equilibration, Assimilation and Accommodation**

For Piaget, knowledge comes from two sources – external and internal. *External knowledge* he also refers to as *physical knowledge* formed from external observations

and interactions with the physical world. He also distinguishes what he calls, *logico-mathematical knowledge*. This is created when a learner establishes mental relationship between objects. This is *internal knowledge*. Schemas inside the learner are mental structures constructed by organising observations, behaviours or thoughts into patterns.

Having developed a view of knowledge, and a structure to contain knowledge, Piaget then defined a process through which each individual experiences stimuli and uses these to produce meaning.

According to Piaget's theory, learning is an active process in which each learner must construct knowledge by interacting with the environment and resolving the conceptual conflicts that arise between what they expect according to their mental schema, and what is observed. Piaget's term *equilibration* is a process by which each learner compensates mentally for each new dilemma.

*Assimilation* is one way the mind may adapt to the learning change and restore equilibrium. If the stimulus is not too different from previous experience it may be combined with, or merely added to, existing schema.

*Accommodation* is another way the mind may respond. The mind may adapt by changing or adding to its mental structures. The mental models may require radical adjustment or new schemes added to them.

In practice, accommodation and assimilation are related and occur together, each process complementing and enhancing the other. A rational, thinking, learner is mentally active, and when a conflict is encountered can enter a state of dis-equilibrium. In this state, challenges come from physical experiences or by discovering conflicts in the internal logico-mathematical knowledge. In general, the stimulation from this will come from outside, but not exclusively. What the learner then does with these conflicts in assimilation or accommodation will determine change to the schemas and ultimately what learning takes place.

This then is Piaget's significant contribution to learning theory. His focus is on the internal world of a student, and the schemas that are built up through experience and activity. The next chapter develops the specific implications of these ideas for physics instruction in particular.

### **2.6.3 The Zone of Proximal Development**

Vygotsky's insights about the relationship between learning and teaching are summarised in a concept referred to as the zone of proximal development. To be effective, he argued, guidance or instruction from teachers or tutors must always be in advance of development, but not arbitrarily so. For a learner, in any context, there is a zone of proximal development. This is a window of potential learning that lies between what he or she can manage to do unaided and what could be done with help. When instruction and instructional activities are appropriately pitched between these two limits, optimal learning takes place. (See Diagram)

In the zone of proximal development, cognitive growth proceeds through participation in activities slightly beyond the competence of the individual. Vygotsky (1978) writes:

Imitation is indispensable. What the child can do in cooperation today he can do alone tomorrow, therefore the only good kind of instruction is that which marches ahead of the development and leads it. It must be aimed not so much at the ripe as at the ripening functions that remains necessary to determine the lowest threshold at which instruction may begin, since a certain minimal ripeness of functions is required, but we must consider the upper threshold as well. Instruction must be oriented towards the future not the past. (p86)

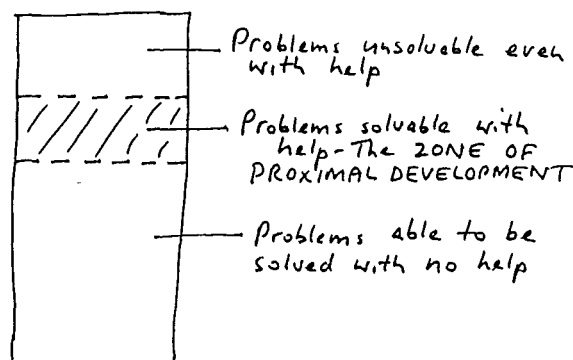


Diagram Illustrating Vygotsky's concept of a *Zone of Proximal development*

Thus Vygotsky's idea of collaboration as acting like a scaffold to build from the known and mastered, into areas where the student has not yet mastered. This term "scaffolding" comes from Jerome Bruner and is a good guide to how to teach. In seeking to define when to best target teaching, Jean Piaget uses the term "teachable moment". Vygotsky's zone of proximal development is a concept of what to teach in relation to the existing and potential skills.

I have quoted at length from Vygotsky's work on the zone of proximal development because of the profound impact this concept has had on the collaborative learning community both in practice and research. Initially collaborative learning research was not based on these ideas, but with the influence of Vygotsky's book in 1978, the collaborative learning community had embraced this idea in particular, as part of a justification for their approach. Indeed it could be argued in some cases, that the research into collaborative learning has in turn helped strengthen and develop the Vygotskian theory and has suggested many new avenues of inquiry. Examples include mathematics education, redesigning of testing methodology, language teaching as well as science (Wells, 1996, 1996b; Cobb and Yackel, 1996; Smagorinsky, 1995).

#### **2.6.4 Social Construction of ideas**

Also associated with Vygotsky is the notion of the *social construction* of ideas. Ideas and concepts are learned and internalised in the process of dialogue and interaction *after* the formal teaching. This dialogue is social in context.

Vygotsky (1978) wrote:

. . . learning awakens a variety of developmental processes that are able to operate *only* when the child is interacting with people in his environment in cooperation with his peers. (p90. Emphasis added)

This shows the high value that Vygotsky places on the social interaction. The cooperative learning movement has drawn on these ideas over the last 15 or so years. Vygotsky emphasised the highly complex and dynamic relationships between individuals in the development and learning process. He argued that external learning processes are converted into internal development processes in the *zone of proximal development*:

. . . which is the distance between the actual development level as determined by independent problem solving and a level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers. (Vygotsky, 1978, p86 italics in the original)

Hence for Vygotsky, collaboration or interaction with more capable individuals, is vital to the process of learning.

This highlights again the main difference between Vygotsky and Piaget which concerns their views on culture. For Vygotsky, activities and experiences become internalised only after a series of transformations:

. . . first, on the social level, and later on, on the individual level; first *between* people (*interpsychological*), and then *inside* . . . (*intrapsychological*) This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relations between human individuals. (Vygotsky, 1978 p57)

Dialogue with others becomes internalised and part of an individual's inner thoughts. Research into these ideas continues in many subject areas. (For examples, see Wells, 1996)

### **2.6.5 Dis-equilibrium**

Vygotsky also sought to describe the mechanism whereby internalisation of ideas and real learning happened.

He believed that when individuals work together in a cooperative setting, certain kinds of conflict occur in people's ideas that creates what he called *cognitive dis-equilibrium*. This in turn further stimulated the growth and development of ideas and concepts. He believed that the act of talking helped to clarify and internalise ideas. This he termed *approbation*, similar to Piaget's concept of assimilation.

### **2.6.6 Semiotic Mediation**

Vygotsky believed that human beings were the products, not just of biology but also their human cultures. Intellectual functioning is the product of a social history. Language and interaction *between* individuals is the key mode by which we as human beings learn and organise our thinking. Group interaction is then vital.

This puts Vygotsky in sharper focus against Piaget. He wrote:

. . . any higher mental function *necessarily* goes through an external stage in its development because it is initially a social function. (Vygotsky, 1997, p105)

Mechanisms rich in the shared understandings of signs and symbols common to a culture are referred to as 'semiotic'. For Vygotsky, semiotic mechanisms, including psychological tools, mediate the social and individual functioning and connect the external and internal, and the social group and the individual. Examples of these mechanisms include:

. . . language; various systems of counting; mnemonic techniques; algebraic simple systems; works of art; writing; schemes, diagrams, maps and mechanical drawings; all sorts of conventional signs and so on.

(Vygotsky, *The Instrumental Method in Psychology* In J Wersch (Ed) *The Concept of Activity in Soviet Psychology* 1981 p137. Quoted in Wells, 1996b.)

These tools have no *inherent* meaning, value or use, but take on meaning through the value and meaning members of a society have attributed to them (Smagornsky, 1995).

Other tools have come to be recognised as significant, for example, the paint brush, the computer, and calendars. These and other tools are seen as central to the assimilation of knowledge through representational activity by a learning and developing individual (John-Steiner and Mahn, 1996).

These tools are not invented by the individual in isolation, but for Vygotsky, they are the products of socio-cultural evolution to which the individuals have access, *only* by being actively engaged in interaction in their communities. By way of simple application, Vygotsky noted that children interacting towards a common goal tend to regulate and assist each other's actions.

### **2.6.7 Inner Speech**

For Vygotsky, the most powerful and versatile semiotic tool is language. Verbal communication is needed in a group for co-ordinating action, and for negotiating and communicating participants' understanding and ideas with respect to their joint activities. This tool also provides a similar resource for the internal actions that participants carry out when they are alone.

When speech (an outer activity) was internalised Vygotsky called this *inner speech*, which he saw as being one of the chief means of mediating certain individual mental activities such as remembering, thinking and reasoning.

### **2.7 Summary and Implications for Physics Instruction**

Vygotsky's perspective sees knowledge as being constructed internally following modelling and example in the social setting. This process is mediated from the external to the internal by tools, the value of which is not inherent, but is contextually, socially and culturally determined. Language is vital for learning.



For the physicist generally however, this does not mean open slather for constructing new knowledge. We cannot just decide what we want and label it “knowledge”. Physical phenomena, which we observe and gather data from, do actually *exist*. Things do ‘fall’, they do ‘move’ relative to each other, masses do ‘exist’ and they interact. There are, however, different ways of looking at the same physical phenomena and representing them symbolically. There are different ways of gathering data. Our frames of reference and the numbers we record are not absolute.

Here are two examples, one largely theoretical in nature and one very practical.

There are at least two fundamentally different mathematical representations of the basic definition of force. One was preferred by Lagrange (differentiation with respect to distance) and one preferred by Newton (differentiation with respect to time). There is no inherently ‘right’ or ‘true’ way of forming a shared understanding of force and motion. There is no making an absolute choice between these two views. Newton’s influence and preference means that the second account is usual. This mental representation is a culturally based, shared understanding, however much it is based on a real world ‘out there’ that exists independently of an observer.

Also, in the teaching and discussion of forces, a common tool is a representation called a *Free Body (Force) Diagram* (commonly abbreviated FBD). This is a way of representing the influences on a body showing their size and direction. Such diagrams are an extremely powerful tool that encapsulates a lot of ideas and helps focus thinking. Such a representation has no separate existence apart from the social history and shared understanding of the physics community. The modeling and example of others is needed for an individual to come to use and appreciate a FBD as a tool for understanding.

Vygotsky’s social constructivist view also has implications for the lecture method of teaching. Getting only one perspective, in a one way communication from a lecture, leaves us somehow truncated in our ability and understanding. Further active engagement with the ideas under discussion is needed before the learner can function independently and claim to have *learned*.

In what has been called an *emergent view* there is a mingling of ideas from both socio-cultural and constructivist views. This is a pragmatic synthesis and acknowledges some changes in the emphasis of the original works, particularly of Vygotsky. Neither view has been shown to fully account for all that is observed in classroom teaching and learning situations. As time goes on, the theories have been adapted and modified, sometimes in many different directions at once. Taken together they are maturing into a theoretical framework which has an increasing usefulness in informing teaching and instructional methodology.

The key ideas described in this chapter have proved useful in guiding physics education research, particularly that involving collaborative learning. These include the notion of schemas, assimilation and accommodation, and the social construction of knowledge. It includes the use of tools and symbolic representation in thinking and interaction. On

this basis a useful model for physics instruction has been developed which has a strong applied focus. This has provided many new insights into how students learn in physics courses.

The next chapter presents an account of this model.

### 3. A Model for Physics Education

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#### 3.1 Introduction

This chapter outlines a model of learning in physics courses. The model draws on conceptual development theory as outlined in Chapter Two, but physics education researchers adapt, combine and modify ideas as needed. They have given this model the label “*the constructivist model*.” In this, a strong socio-cultural thrust is added to the philosophical concept of constructivism (Redish, 1996a; McDermott, 1993a; Leonard et al, 1994). One part of what physicists mean by “*constructivist*” is “collaborative learning”. The educational research based on Vygotsky’s socio-cultural theory suggests that giving students the chance to interact with ideas and concepts in structured small group activities, following formal instruction, helps to develop and cement their ideas and learning. See for example Heller et al (1992b) and Johnson et al (1998a). This has been given the general label “collaborative learning”.

As stated in Chapter Two, this research was not originally *based on* the theory, but conceptual development theory, particularly the socio-cultural perspective, is now an accepted part of the justification for the collaborative learning approach. Indeed, it could be argued in some cases, that the research into collaborative learning has in turn helped strengthen and develop some parts of cognitive theory.

The final section of this chapter sets out some specific implications of this model of learning in physics when it is applied to the tutorial component of a physics course, with special reference to the New Zealand setting.

#### 3.2 Constructivism and the Transmission Models of Learning

In the context of physics education research projects, terms and definitions from the theoretical basis sometimes become blurred. By way of some background, we need to consider the issue of constructivism as it appears in recent debate over the nature of science education in general, and physics education in particular.

Constructivism has come to be a popular and widely held view of knowledge and learning (Driver et al, 1994; Matthews, 1994). Some have argued that this is now the dominant view in science education (Dettrick, 1998; Leonard, 1998). Certainly some teacher education programmes claim to provide a constructivist oriented training for teachers. However, many scientists, some involved in education, have found an extreme expression of this, so called *radical constructivism* quite unpalatable. The principal reason for this is its challenge to the notion of an external reality: that no amount of experience, experimentation or thinking can *prove* anything. Science on the other hand generally assumes an external reality and assumes it is well behaved and capable of being explained. For a good statement of some of these issues see Longbottom and Butler (1998b). The debate between the *realist* and *instrumentalist* views of science is focused on these issues. There have been several bitter and intense exchanges of ideas on these issues among educational researchers. For a statement of the anti constructivist position, see Matthews (1994) and for a constructivist’s response

see Bell (1995). Part of the reason for the intensity of the conflict, is that the position adopted has a significant influence on the curriculum that is developed, and on the teaching methodology prescribed.

The constructivist view is at odds with a view of science education commonly referred to as the *transmission model* for learning. Knowledge is seen as being ‘transmitted’ from teacher to learner. Some implications of this model may be summarised briefly with these statements which are adapted from Redish (1996b):

**The Transmission Model for Learning**

1. Previous knowledge is not relevant. (The tabula rasa or blank slate assumption about students.)
2. Students either know something or they don’t.
3. The student is idealised. They are well motivated and willing to learn. (If they aren’t like this it is their fault.)
4. Students will learn from their mistakes. (They are assumed to be metacognitive.)
5. Scientific thought and rational thinking are taken to be obvious and natural.

Arguments in favour of this view continue to be strongly expressed. For example, Illman (1998) speaks strongly in favour of a transmission view. He puts forward this statement for debate with those of a constructivist perspective:

Knowledge transmission should be viewed as **one** legitimate and recommendable type of science education in the 21<sup>st</sup> Century. p5 (emphasis in the original.)

However, in spite of the conflict between these two views, many of the so-called conflicts between science and constructivism become a non-issue at the level of the classroom practitioner. Here is a summary statement of the main features of the constructivist model as is common in physics education research:

**A Constructivist Model for Learning**

1. Students construct their knowledge by processing the information they receive.
2. What students construct depends on the context – including the students' mental states.
3. Producing significant conceptual change is difficult and can be facilitated through a variety of known mechanisms.
4. Individuals show a significant variation in their style of learning along a number of dimensions.
5. For most individuals, learning is most effectively carried out via social interactions.

Redish

(1996b)

This is a standard account of the constructivist model as used in the context of many significant physics education research projects and in a variety of different courses and institutions. For example, see Halloun and Hestenes (1985), Leonard et al (1994), McDermott (1993b) and Gautreau and Novemsky (1997).

In this account, which has been given the label ‘constructivist’, point 5 is out of place when compared to the theorists version of constructivism as found in conceptual development theory. Point 5 refers to *social interactions* being significant for *individual* learning. Some physics educators would go so far as to say such interaction

is *essential*. Taken as a whole then, this five-point model represents a blend of Vygotsky's socio-cultural view and Piaget's socio-constructivist view. Pragmatically, researchers have chosen fragments out of formal educational theory to develop a model of learning in physics.

### 3.3 A 'Model' of Learning

Some clarification of terms may be appropriate here. The physics profession in general has a fairly consistent view of a 'model' in the work of science. There is evidence in some writings in physics education research that physicists have sought to define a similar *kind* of model for work in educational research. This model then becomes the basis for research and curriculum development.

### 3.4 The Nature of Models in Physics

#### A 'Model' of a Model

The following description of a "model" in physics (as a scientific discipline) is adapted from a variety of sources, principally Sciamanda (1996).

##### A Model in Physics

1. It is a human construct, the offspring of both our *experience* and our *imagination*.
2. It is *quantitative* and speaks of freely defined, measurable properties of matter.
3. It has both an *empirical* and a *conceptual* usefulness: it presents a testable numerical equality involving the numbers generated by specified measuring devices, and it offers a conceptual framework for associating a deeper meaning with these numbers.
4. The empirical usefulness of a model is a matter of experimental verification, and once verified this usefulness will remain; future models of a wider scope will generally include it as a special case.
5. The conceptual usefulness of a model can be a cultural matter, a matter of institutional and personal taste.

This first statement seeks to take into account the nature of 20th Century physics with the uncertainties and issues introduced by Quantum Theory. The type and scope of conceptual models can be limited by the capacity of the observer. More creativity and imagination is needed as the physicist probes deeper into the nature and behaviour of reality. Abstractions and cross-fertilisations of ideas and concepts become more complex and subtle.

David Hestenes writes:

A model is a surrogate object, a conceptual representation of the real thing.  
Hestenes, (1987) p441

Hestenes sees a model as having various states and relationships between these states, which represent and 'model' the behaviour of the corresponding physical system. Various numerical values can be determined for states, and the relationships between these states are usually expressible quantitatively mathematical. Predictions can be made and tested.

The emphasis of models in the discipline of physics is on numbers and mathematical relationships. Physics educational researchers have tried to emulate this in educational contexts, with new forms of finely targeted quantitative conceptual assessment tools which produce numerical measures of conceptual understanding. One such assessment is the *Force Concept Inventory*, a carefully constructed set of items that makes students choose between Newtonian (or scientific) concepts and non-Newtonian concepts (Hestenes et al, 1992). Another is the *Force and Motion Conceptual Evaluation* (described in detail in Sokoloff and Thornton, 1998). There are other assessments that have been developed for electrical concepts, energy and waves. They are based on a much clearer idea of how physics knowledge is constructed, and hence there is more clarity about *what* is being assessed. They were developed over several years involving trials with thousands of students in controlled situations. This refinement process has helped develop the tests so as to reduce the number of false positives (i.e. students getting answers correct for the wrong reasons).

These tests can now provide a more precise indicator of understanding in a number of defined conceptual areas. What has become known as the *Hake Plot* gives a measure of the improvement in conceptual understanding. For a given course, pre-test and post-test results are compared by calculating the *average normalised gain*. This is defined as the ratio of the actual average gain ( $\% \text{post-test} - \% \text{pre-test}$ ) to the maximum possible average gain ( $100 - \% \text{pre-test}$ ). A Hake plot seeks to compare the results of *different* courses by graphing the average normalised gain against the pre-test result. A full description of this is in Hake (1998) where 62 courses totaling 6542 students are reported in this way. This approach has provided information to enable comparison of different teaching methodologies.

However, as well as seeking quantitative measures, there have also been efforts to develop approaches that allow for qualitative results, for example Patricia Heller's work on cooperative small groups (Heller et al, 1992b) and Lisa Novemsky's recorded small group sessions (Gatreau and Novemsky, 1997). Even in this type of analysis, there is a role for numerical results. Observations and measurements have been carried out to examine patterns in student interaction. These are tied to measurable results, the qualitative observations eventually being measured quantitatively.

In physics, a model may be used to convey information or to describe a phenomenon without the pretense of being unique, complete, or ultimate. A model is as good as the data on which it is based, and on adequately reflecting the phenomenon for which it is constructed (Sciamanda, 1996). Usually such data is in numerical form. This is the basis from which physicists have sought to develop and use an educational model of how students learn.

### **3.5 Physics Education Models of Learning: A Blend of the Theories**

Physics education models represent a blending of the views put forward in writings by educational theorists. They have tended to pick and choose a few key themes without much reference to their formal theoretical roots. As in their use of physics models in the study of physics itself, educational models of student learning are put to the test,

used to develop new possibilities, and in the applied context, used to develop new modes of instruction.

Some features of the model used are often described as ‘intuitive’ and ‘obvious’ to anyone who has taught and thoughtfully reflected on their experience. Other features are almost ‘counter intuitive’ in their implications. There are a number of significant programmes seeking to bring the same rigorous scrutiny to classroom instructional theory in physics, to that brought to bear on laboratory physics research. This has been healthy. There have been some positive results in a range of diverse projects including Physics by Inquiry, The Modelling Workshop, Overview Case Studies, Peer Instruction and many others. (For an overview see Redish, 1996a.)

All these projects have followed an interactive process involving research, teaching methodology development and subsequent evaluation with formal pre-testing and post-testing of certain concepts. Results of the evaluations have been used to develop the working model and to further refine instructional methods. All of these projects have used a version of the constructivist model close to that described above, and all have demonstrated significant improvements in instructional outcomes.

The blended view as I have described it is a pragmatic and applied working model developed as the theoretical ideas are interpreted, and certain implications proposed. What follows is an outline of some of the implications for the physics classroom based on the model described above.

### **3.6 The Model Applied**

The working model for much instruction *in practice* follows the transmissionist view as described earlier in this chapter (Hake, 1998; Halloun and Hestenes, 1985). Hence instruction tends to be one way with the instructor active, and the students passive. The alternative constructivist model as presented, implies a different approach to what happens in the classroom.

Students tend to organise their experiences and observations into mental models. These mental models may contain incomplete and contradictory ideas. Because of the tendency for students to become inactive, formal instruction such as a traditional lecture is not enough to shift misconceptions that are part of the mental models of most students. (Halloun and Hestenes, 1985.)

These mental models of the students are developed and clarified by social interaction with ideas and other people. Through an active process of thinking and communicating, these ideas and contradictions are clarified. Tools of thinking (diagrams, words, concepts, computers, graphs etc) have an important part to play in this process. The role modeling and example of others in a group, and of the teachers or other experts, is vital in the process also. Effective teaching will involve group interactions which assist change in the mental models of students from one state to another which better reflects reality.

Therefore, part of the learning activity should consist of new problems and challenges presented in a group context, to give opportunity for the necessary social interaction. The level of these problems should be such that individuals are not able to accomplish the problems on their own, but are able to complete them with the aid of the group. The problems should be designed to challenge concepts and ideas in the mental models of the students. The student involved in active learning in the social context of the group will experience the development and growth of their mental models. Without this outside stimulation, most students will experience little real and permanent change in their mental models.

Careful consideration should be given to the context of ideas development. An example may help clarify this.

Mark, an eight year old participant in a research project (Chirnside, 1998), when being interviewed about his understanding of forces and energy, asked his own question:

Mark:	You need to have air present to hear things don't you?
Interviewer:	What do you think?
Mark:	Well in space you can't hear the noise of the rockets because there is no air.
Interviewer:	What do you know about how whales speak?
Mark:	[Pause.] Oh I see, sound can travel through water as well. [Pause.] So can it travel through anything, not just air?
Interviewer:	Pretty well I suppose. Scientists say <i>sound needs a medium to travel through</i> .

This simple example shows the effect of an interaction in a social environment providing a challenge to change and develop the mental model of the student. The initial state shows contradictory understandings held simultaneously in Mark's thinking, each relating to two different contexts. In the intermediate state, interaction with another person helps expose the contradiction, enabling a change to occur.



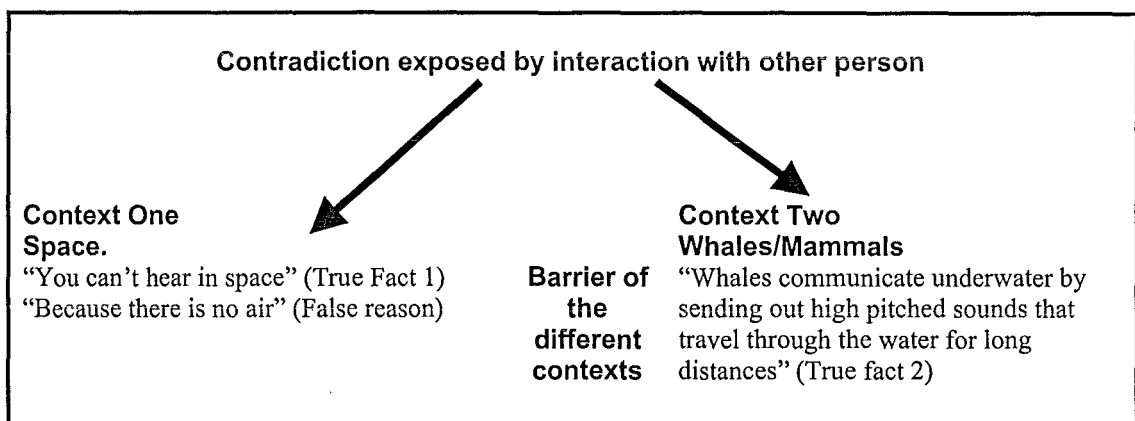
This can be illustrated visually:

### Initial State:

<b>Context One</b> <b>Space.</b> “You can’t hear in space” (True Fact 1) “Because there is no air” (False reason)	<b>Barrier of the different contexts</b>	<b>Context Two</b> <b>Whales/Mammals</b> “Whales communicate underwater by sending out high pitched sounds that travel through the water for long distances” (True fact 2)
--	--	--

### Intermediate State:

Challenge:



### Final State:

True facts:	You can’t hear sound in space Whales can make sounds underwater.
True reason:	Because sound needs a medium to travel through.

The final state of understanding then has sorted out and generalised information from these two different contexts. Efficient, effective and lasting learning requires that the mental models held by an individual grow and develop with ideas, facts and opinions being exposed in a range of possible contexts. For this process to occur, social interaction is vital, and small group work is a manageable way to allow for and encourage this.

### 3.7 Summary and Overview: So How Then Should We Teach During the Tutorial Component of a Course?

This concludes the statement of a model of student learning based on the contribution of Piaget and Vygotsky to conceptual development theory.

Our focus here is on the tutorial component of an introductory physics course. The question is: *What is an effective way to run tutorials to maximise learning?*

Following work by Heller et al (1992b) these requirements should be fulfilled:

1. Following formal instruction, students should spend at least part of their time working in small groups, actively interacting with one another and the work in hand. (Rather than only working competitively and individually.)  
Problems could be provided on just one sheet of paper with one group solution being required from each group. (To help develop true collaboration rather than the group being a number of individuals.)
2. Groups would need to be properly structured, with the role of the tutor being more of a facilitator. (Rather than merely a source of answers.)
3. Active strategies for small group work are needed which tutors could teach, model and assist. (Since many students don't have the required skills.)
4. Problems should be challenging, but not too much so. (Not a simple one step formula based question.)
5. Concepts should be presented in a variety of contexts that challenge thinking. (Rather than relying on rote learning.)
6. Clear communication of the reasons and motivation behind this type of activity needs to be carried out. This is referred to as meta-communication – communication about the process - what you are doing and why. (Students won't automatically understand and may even resist this way of working.)
7. An explicit model for problem solving needs to be presented and modelled.

### **3.8 DISCUSSION: The New Zealand Context**

The research programmes that I have described have mainly taken place in America. A much lesser number have also come from Europe (principally Germany) and South Africa. There are some significant differences between the educational culture in America and in this country. This fact needs to be taken into account in evaluating the results from the various trials.

Firstly, science education at high school level in the United States usually takes place over three years, the first year being a biology course, second year a chemistry course, and the third year a physics course. This structure is radically different from the system here, where a general science course is followed for three years, with some physics taught each year, followed by specialisation at Year 12.

This has a number of consequences. Students arrive at Year 12 courses having often had a reasonable exposure to physics, which may include such topics as force, motion and electricity. This sometimes has the effect of inoculating students *against* understanding the ideas in some contexts. They equate knowing some terms and ideas with knowing the concepts, and often lack an overview of the subject.

A similar observation can be made at university level. Our early test results in PHYS102, as well as anecdotal evidence from tutors in the tutorials suggests that a number of students have come in with a background of many half-formed ideas. They know some formulas, they know some words and terminology, but have not really gained an understanding of the basic concepts. They equate knowing a formula with knowing the ideas. Or put another way, they lack a global overview of the subject, their ideas being fragmentary, and lacking in coherence.

There is also a generally different style of teaching between High Schools in America and New Zealand. The American approach is more formal and teacher centred, whereas in New Zealand classrooms, there is a lot more activity and interaction, especially after reforms in curriculum and methodology over the past fifteen years.

Hence we can learn from educational research and experience in America. But the differences in educational culture and course structures are real and need to be considered as changes are implemented in New Zealand.

## **4. The Redesign of PHYS102 Tutorials**

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### **4.1 Introduction**

This chapter describes the background to the changes to PHYS102 tutorials in 1998.

### **4.2 Background to the Changes to PHYS102**

The changes to PHYS102 were planned by the two lecturers involved in the courses (Professor J Baggaley and Assoc Professor P Cotterell), the head of the Department of Physics and Astronomy (Professor P H Butler) and myself in the role of ‘tutorial coordinator’. We also consulted with the five postgraduate students who were to be the tutors. In implementing the changes, there were several factors which we decided were relevant.

First was the experience from the previous year with PHYS103. In these tutorials the small group work was well received by many students and seemed to be effective. These conclusions came from course feedback and anecdotal evidence from informal observations. In our initial discussion while planning for the changes, I introduced some background ideas based on research into small groups, but with a certain reserve, recognising that there were significant differences between overseas institutions where the research took place and the student culture in this country. After some consideration it was decided that collaborative small group work *was* to be a central part of the tutorials. A practical reason for this was the fact that small group work takes certain pressures *off* the instructor and gives more opportunity for the student to be actively involved, rather than just a passive observer.

Another factor requiring consideration was the complex relationship between student motivation and whether or not credit was given for tutorial attendance and tutorial problems. This was related to what assessment took place during the tutorials as well. We decided to include two small co-operative problem sheets in the tutorial assessment.

We believed that while change was necessary, we did not want it to be more than the system or the students were able to adapt to.

To help orient the tutors I held a two-hour seminar to discuss the ideas and rationale behind small group work. It was recognised that what we proposed represented a huge change in the role of the tutors. Whereas previously the tutors were the focus of attention as they went over problems at the whiteboard or answered questions, now they were more in the role of a facilitator. The changes to the small group work approach were explained to the tutors, and within this framework they were free to arrange their tutorials as they wished. I held brief weekly feedback meetings with the tutors during the course.

It was decided to continue the practice of setting weekly sets of homework problems. Tutors marked these if they were handed in on time. These would not count either towards course completion or towards the tutorial grade. This decision probably meant

there was a lower hand in rate. However the problem with giving credit is that students are known to simply copy answers from other students just to get them handed in. Answers were available in the library the week following the due date. It may well be that a significant number of students eventually looked at the problems, and used the answers in their study for final examinations. These views are supported by student feedback during the interviews conducted to help evaluate the new tutorial structure.

As well as the two assessed cooperative problem sheets, there were two formally assessed individual tests and two formally assessed homework assignments. The total towards the course grade was 10%.

### **4.3 Three Key Changes**

After much discussion, the style and content of the new look PHYS102 tutorials was finalised. In the main, the specific changes were adapted from a cluster of ideas as developed in the introductory physics course at the University of Minnesota (Heller et al, 1992b; Heller and Hollabaugh 1992a). In harmony with the model presented in the last chapter, we introduced three new key ingredients. Firstly there was a new type of problem. Next, we proposed that students work on these problems during the tutorials in small collaborative groups, rather than competitively or individually. Tutors were to work with the students to help the small groups to function. Finally, we sought to provide tools for problem solving in the form of an explicit step by step strategy. This strategy was to be actively modelled by the tutors.

#### **4.3.1 Context Rich Problems**

The work at Minnesota had indicated the success of a new type of problem. These were referred to as *context rich* problems and had several features:

1. They were in the form of a short narrative story, usually written in the first person.
2. They were generally more difficult than the average student could cope with on their own.
3. They were not solvable in one step merely by plugging numbers into formulae.
4. They often included extra data that was not needed or omitted data that would be commonly known.

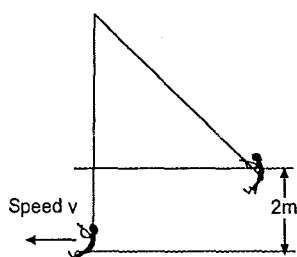
We decided to use context rich problems of this type in the problem sessions. These were to be used to develop ideas and concepts. The small course grade component mentioned above was to encourage students to take these activities seriously, but the general purpose of these problems was *not* for assessment.

Here is a sample problem of this type:

### PHYS 102:

### ASSESSED PROBLEM SHEET 1.

- Answer on sheet provided.
- Work together in a group handing in one combined solution.
- Assign roles, but you choose how well you work with these.
- Time: 20 minutes. Fill in the times taken.
- Full access to notes, textbook is allowed.



#### The Catburglar's grappling hook

Joe the midnight catburglar comes to you for some advice. He has to develop a lightweight grappling hook and cord from fine nylon strands, each strand of which can withstand a maximum tension of 4.5N. He requires a length of 5 m and will need to swing from heights of at most 2 m (above the lowest position of the rope) as shown.

You do some calculations for him (against your better judgement of course) to recommend how many strands should make up the cord. You pause for a moment and realise you are short one vital piece of information. You make a sensible estimate and then work on a solution.

This is the question: *Assuming you are truthful, what do you tell him?*

#### A sample *context rich* physics problem

For three other examples see the questionnaire reproduced in Appendix Four.

This problem is a little unusual in that usually no pictures are included, so the students are forced to think carefully about the situation and to create their own representations such as diagrams or graphs. Also noteworthy is the general type of question at the end of this example. Students have to think actively to decide what they need to do to be able to answer this question.

This is in contrast to the more sterile and abstract problems often common in physics courses:

A 60 kg mass is swung on the end of a 5 m cord from rest, a height of 2 m above the lowest point in the swing.

What is the maximum tension in the string at the lowest point on its path?

#### A sample *traditional* physics textbook problem

The Minnesota research suggested that students working together were able to handle problems that were more difficult than members of the groups could have handled on their own (Heller and Hollabaugh, 1992a).

#### **4.3.2 Structured Group Work**

The second major change was the introduction of small group work into the tutorial sessions. From the experience during the PHYS103 tutorials in 1997, we were aware that this aspect would need careful planning.

Johnson et al (1998b) presents a summary of the key outcomes from small group work. This list is based on a survey of over 550 studies in cooperative learning. While it is originally from a high school perspective, Johnson and Johnson (1998a) also apply a similar analysis to the American college classroom. Some of these positive outcomes of group work include the following:

1. Higher achievement and increased retention.
2. More frequent higher-level reasoning, deeper-level understanding, and critical thinking.
3. More on-task and less disruptive behaviour.
4. Greater achievement motivation and intrinsic motivation to learn.
5. Greater ability to view situations from others perspectives.
6. More positive, accepting and supportive relationships with peers regardless of ethnic, sex, ability, social class or handicap differences.
7. Greater social support.
8. More positive attitudes toward teachers, principals and other school personnel.
9. More positive attitudes toward subject areas, learning and school.
10. Greater psychological health, adjustment and well-being.
11. More positive self-esteem based on basic self-acceptance.
12. Greater social competencies.

Quoted in Johnson et al (1998b) from Johnson and Johnson *Cooperation and Competition* Edina, MN Interaction Books 1989.

However, they also warn that these outcomes do not occur by accident, and their studies report that well functioning small groups need careful structuring. Teachers and tutors need to be actively involved to help groups function. Some of their advice for teachers includes:

Teachers may structure positive interdependence by:

1. establishing mutual goals (eg “learn and make sure all other group members learn”).
2. giving joint rewards (eg if all group members achieve above the criteria, each will receive bonus points).
3. having shared resources (eg one paper for each group, or each member receives part of the required information).
4. using assigned roles (eg summariser, encourager of participation, elaborator).

(Johnson et al 1998b – slightly reformatted)

With these kinds of findings in mind, certain decisions were taken as to how the tutorials were to be organised in order to encourage group work.

**Shared Resources.** Firstly, as a way of encouraging true collaboration, groups were structured in such a way as to work together on *one* written solution to a problem. The aim was to encourage collaborative *whole* group work on a problem rather than individuals working on their own solutions and only sometimes sharing with a neighbour.

This represented an enormous change from the usual way of working. The responses in the interviews showed that most students (10 out of the 11 interviewed) are used to working only individually or competitively, or at best in short term poorly structured group situations.

**Assigned Roles.** To assist in the development of a positive atmosphere of cooperative learning, a list of group roles was prepared. There are many possible versions of such a list, as this is a common tool among teachers to help groups function. We chose a list of four roles: manager, recorder/checker, skeptic and energiser/summariser.

Each of these roles was listed in a table with a few ideas to describe the role and some phrases to help students understand what the role 'sounds like' when in operation.

Here is the detail for the 'manager' role:

ROLE	WHAT IT SOUNDS LIKE
<b>Manager</b> <ul style="list-style-type: none"><li>• Direct the sequence of steps.</li><li>• Keep your group "on-track."</li><li>• Make sure everyone in your group participates.</li><li>• Watch the time spent on each step.</li></ul>	"Let's come back to this later if we have time." "We need to move on to the next step." "Chris, what do you think about this idea?"

The full list of roles and the descriptions which we adopted for PHYS102 is printed in Appendix Two.

This approach was discussed with the tutors in the orientation seminar prior to the start of the course. We also discussed some basic approaches to helping small groups to function by using these roles. The tutors were given freedom to choose the level at which they would work with these. Each time the students worked on a cooperative problem sheet, they were to fill in their names next to one or more of the roles on the sheet before handing it in.

**Joint Rewards.** In our planning we were initially concerned that students would not take the process seriously. As a small token gesture to try to offset this, there was a small credit given for two of the cooperative problem sheet exercises as described above. This amounted to only one third of 10%, but feedback in the interviews suggested this was still worthwhile in raising student motivation.



### **4.3.3 An Explicit Problem Solving Strategy**

The third key feature of the redesigned tutorials is the use of a specific problem solving strategy.

Van Heuvelen (1991) has written describing the difference between the way that the novice and the expert approach physics problems.

The novice tends to apply a semi-random search strategy to try to find relevant equations and then to substitute numbers in an attempt to reach an answer. Specific consideration of the underlying physical principles involved is often omitted. This finding was confirmed with some simple analysis of working on problem sheets during the PHYS102 tutorials. Over half the students lapsed back into a novice-style approach when working on a problem sheet without full guidelines on the strategy or specific reminders from the tutor.

The expert, on the other hand, makes use of a range of mental tools and methods. These include analysis of the physical principles involved, elimination of surplus data, simplification of the situation down to its essentials and the use of diagrams and other representations. However, the use of some of these tools is often so quick and fleeting that an observer would not notice them. Often in the classroom teachers and tutors can easily gloss over the steps in the solution of problems without realising they are not intuitively obvious to their students.

Heller and Hollabaugh (1992a) report that the use of a strategy that is made explicit (rather than just being implied) can help students gain the skills they need. In planning the PHYS102 tutorials we sought to provide such a strategy. In designing the small group problems we sought to design the sheets in such a way as to encourage the use of the strategy.

The approach we used had five steps:

1. Comprehend the problem.
2. Represent the problem in formal terms.
3. Plan a solution.
4. Execute the plan.
5. Interpret and evaluate the solution.

A copy of the full version as provided to the students is reproduced in Appendix Three.

Tutors were to strongly model the use of the strategy in the way they spoke to the students and solved problems. The problem sheets were written to take advantage of the ideas in the strategy. At times during lectures, when appropriate, the lecturers would make use of the five steps in an explicit way. Some of the formal testing required students to fully develop each step in the process. On the other hand, however, the steps in the strategy were seen as a guide only, and while they were encouraged, they were not in any way coercively enforced.

#### **4.4 Other Course Components**

This completes an overview of the changes to the PHYS102 tutorials. Apart from these changes, the laboratory component, the style of the final exam, and the scope and sequence of the lectures remained the same.

Any other details not specified in the outline above were not prescribed, but were left to the discretion and judgement of the tutors. These included the specific size of the group (which was generally three or four) and how groups were formed. Most tutors let groups form themselves. The occasional situation of an individual student who would just not cooperate as part of a group and who insisted on working solo was managed in a low key way, generally by just letting the individual work as he or she wanted. Tutor feedback indicated that this was a rare occurrence.

Encouragement and gentle intervention was always used rather than any heavy handedness. There were a number of students unhappy for one reason or another with their tutorial, (about twenty) that were solved by shifting students into another tutorial with a different group of students.

The small groups sessions occupied about half of each tutorial session, during which time the groups would work on one cooperative problem sheet. The other half of the time was used according to the discretion of the tutor and in negotiation with the students. This generally involved answering specific questions from students or working on answers to homework problems.

The fact that things were different in the tutorials was obvious to the students right from the start. Through our tutorial information handout (reproduced in Appendix One) we sought to make it clear that there was a clear rationale for the way things were being done. This general communication included not just *what* we were doing but also *why*. Feedback from the students indicated that they appreciated this and that it was helpful in adjusting to the changes.

The learning of the students was seen as paramount, and the small group activities and the facilitation of the tutors were aimed to create a positive and supportive environment for this learning to take place.

## **5. Research Methodology**

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### **5.1 Research Aims and Objectives**

The aim of this research was to explore the nature of student learning in the restructured PHYS102 tutorials. The particular focus was the collaborative small group work, and how it influenced student learning. There were two practical uses to these findings. Firstly to enable evaluation of the success or otherwise of the changes to PHYS102 and secondly, to assist in further improvement to the course structure.

It was important that there be minimal intrusion into the operation of the tutorials in the carrying out of any observations or data gathering.

### **5.2 Data Collection**

Data was collected in two different ways.

Firstly, to gain a picture of the effect of the groups from the point of view of the student, eleven PHYS102 students completed a questionnaire on matters relating to the new style PHYS102 tutorials. On the basis of the responses in the questionnaire, an interview was recorded with each student. This procedure was suggested in Gatreau and Novemsky (1997) and refined by suggestions from Professor Graham Nuthall (see for example Nuthall and Alton-Lee, 1994). The learning process is complex and is affected by many variables. These interviews were designed to help gain some insights from the world of the student and see things from their perspective.

Secondly, several small group sessions were recorded. This was to gather some information about the dynamics of small group work.

### **5.3 The Student Interviews**

To recruit students to take part in this process, I first visited both lecture streams and talked briefly about the purpose of the interviews. I then visited the tutorials and made appointments with students who were willing to take part. I had a little difficulty in getting volunteers, as I was reluctant to put any hint of coercion into my request. However, I was able to schedule six students before the final exams and six after the exams. One did not turn up.

The final eleven students who participated did represent a reasonable cross section from the course. There were six females and five males, ranging from first year students straight from school to older first year students. There were three students who had studied other non-science subjects at up to stage three level. Two of the eleven had no previous science background beyond Form Five.

The questions in the questionnaire covered attitudes and feelings about the problem solving strategy, the problem sheets, the type of problems and the small group sessions.

#### **5.4 Questionnaire Construction**

The questionnaire was designed to be open ended and to give students a chance to respond by raising matters that they considered significant. The interviews that followed probed for further detail and raised any new matters of interest that students may not have commented on.

The questionnaire began with a standard rubric and a statement of purpose:

*(As reproduced here, the questionnaire text is shaded in grey.  
The full version is reproduced in Appendix Four)*

### **THE EVALUATION OF PHYS102 TUTORIALS 1998 QUESTIONNAIRE**

*Note: You are invited to participate in this evaluation by completing the following questionnaire. This will be followed by a brief interview based on some of the comments in the interview. Omit any questions you wish to.*

*The aim of the project is to gather data on student attitudes towards the tutorials and their effectiveness or otherwise. The results of the questionnaire and the interview will be anonymous in the sense that you will not be identified individually without your consent. By completing the questionnaire however it will be understood that you have consented to participate in this evaluation and that you consent to publication of the results of this evaluation with the understanding that anonymity will be preserved.*

The rest of the questionnaire was divided into a number of sections.

The first section focused on the problem solving strategy. It included an information statement and a question. The information statement was designed to provide a small amount of direction to the students without preempting their responses. Blank space was left between each question.

**INFORMATION:** For the first part of the course the tutorials were set up in such a way that for part of each tutorial work was carried out in small groups on a single problem. It was expected that students should follow the guidelines of the problem solving strategy.

1. How useful did you find the problem solving strategy?

The second section related to the problem sheets and began with a reproduced copy of three of the questions from them. This was to serve as a reminder to the students which problems the questionnaire was referring to.

### **The problem sheets**

2. Consider the Tarzan and Jane problem or the Lone Ranger Problems or the Aircraft Takeoff problems:  
DO NOT DO THESE PROBLEMS NOW.

## **The Lone Ranger and Tonto: Problem 2**

Instructions: On the sheet provided, work on this problem using the full problem solving strategy steps from Tutorial 1.

Tired at working for McDonalds you take on a job as a technical consultant for an early-morning cartoon series for children to make sure that the science is correct. In the script, a wagon containing two boxes of gold (total mass of 150 kg) has been cut loose from the horses by an outlaw. The wagon starts from rest 50 metres up a hill with a  $6^\circ$  slope. The outlaw plans to have the wagon roll down the hill and across the level ground and then crash into a canyon where his confederates wait. But in a tree 40 meters from the edge of the canyon wait the Lone Ranger (mass 80 kg) and Tonto (mass 70 kg). They drop vertically into the wagon as it passes beneath them. The script states that it takes the Lone Ranger and Tonto 5 seconds to grab the gold and jump out of the wagon, but is this correct? You assume that the wagon rolls with negligible friction.

## **Tarzan and Jane.**

Instructions: As above. This problem is similar but different to the one above.

Because of your concern that incorrect science is being taught to children when they watch cartoons on TV, you have joined a committee which is reviewing a new cartoon version of Tarzan. In this episode, Tarzan is on the ground in front of a herd of stampeding elephants. Just in time Jane, who is up in a tall tree, sees him. She grabs a convenient vine and swings towards Tarzan, who has twice her mass, to save him. Luckily, the lowest point of her swing is just where Tarzan is standing. When she reaches him, he grabs her and the vine. They both continue to swing to safety over the elephants up to a height which looks to be about  $1/2$  that of Jane's original position. To decide if you going to approve this cartoon, calculate the maximum height Tarzan and Jane can swing as a fraction of her initial height.

Extra: Do on your own. How much does the tension in the vine increase from before Jane picks up Tarzan until afterwards?

For this problem, hand in a clearly named group answer showing evidence of all the steps outlined in last week's tutorial handout.

## **Catapult assisted takeoffs.**

You have been asked to assist in a design project for a new catapult which will be used to launch a Navy jet from an aircraft carrier. The catapult is 100 m long and the aircraft is 23 tonnes. For takeoff the aircraft requires a minimum speed of  $90 \text{ ms}^{-1}$  and can provide a maximum thrust of 96 kN. Initial tests show the catapult can provide about 800 kN. Make a recommendation: is this enough force to launch the jet?

This was followed by a number of general, un-numbered questions on group-work, the type of problems and tutorials overall.

**In these problem sessions, comment on:**

How well the group worked

How much you felt you learned

How successful you felt you were

How did you find the type of problems set in tutorials?

How have they aided your learning?

How have they hindered your learning?

**Small Group Work**

What do you think are the pros and cons of working together in a small group?

What factors make a small group actually work well?

**Tutorials**

What do you think is the main function of tutorials?

These questions were designed to touch on the significant areas of interest (the small group interaction and the type of problems) several times from more than one angle.

Following this there was a section of questions using a 1 – 5 scale on issues related to learning about physics and physics problem solving. These statements were adapted from Redish et al (1998) which contained a survey of student expectations in physics.

**Read each of these statements and rate each one on a 1 – 5 scale as indicated**

1: Strongly Disagree 2: Disagree 3: Neutral 4: Agree 5: Strongly Agree

- Answer the questions by circling the number that best expresses your feeling.  
Work quickly. Don't over-elaborate the meaning of each statement.
- They are meant to be taken as straightforward and simple. If you don't understand a statement, leave it blank.
- If you understand, but have no strong opinion, circle 3.
- If an item combines two statements and you disagree with either one, choose 1 or 2.

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1. All I need to do to understand most of the basic ideas in this course is just to read the text, work most of the problems and/or to pay close attention to the lectures.	1 - 2 - 3 - 4 - 5
2. I go over my class notes carefully to prepare for tests in this course.	1 - 2 - 3 - 4 - 5
3. Problem solving in Physics basically means matching problems with facts or equations and then substituting the values to get a number.	1 - 2 - 3 - 4 - 5
4. Learning Physics has made me change some of my ideas about how the physical world works.	1 - 2 - 3 - 4 - 5
5. I read the text in detail and work through many of the examples given there.	1 - 2 - 3 - 4 - 5
6. In this course I do not expect to understand equations in an intuitive sense, they just have to be taken as given.	1 - 2 - 3 - 4 - 5
7. Learning Physics is a matter of acquiring knowledge that is specifically located in the material given in class and/or in the text book.	1 - 2 - 3 - 4 - 5
8. Only a few specially qualified people are capable of really understanding Physics.	1 - 2 - 3 - 4 - 5
9. The most important thing in solving a Physics problem is finding the right equation to use.	1 - 2 - 3 - 4 - 5

- |  |                   |
|--|-------------------|
| 10. If I don't remember a particular equation needed for a problem in an exam there is nothing much I can do legally, to come up with it.                | 1 - 2 - 3 - 4 - 5 |
| 11. The main skill I get out of this course is learning to solve Physics problems.   | 1 - 2 - 3 - 4 - 5 |
| 12. Learning Physics helps me understand situations in my every day life.  | 1 - 2 - 3 - 4 - 5 |
| 13. A problem in this course is being able to memorise all the information I need to know.   | 1 - 2 - 3 - 4 - 5 |
| 14. Learning Physics requires that I substantially re-think, re-structure and re-organise the information that is given out in class and/or in the text. | 1 - 2 - 3 - 4 - 5 |

In the analysis I did not use these results as the sample of students was too small for this kind of purpose. This is an avenue of inquiry for further research.

The final section sought to raise some issues that may have been related in the students' mind and could have influenced the attitudes and motivation of the student. These questions asked about homework problems, test preparation and grades.

#### **RELATED ISSUES:**

##### **Studying for Tests**

What activities do you engage in to prepare for tests?

##### **Problem Solving**

What sorts of approaches do you use to solve problems?

##### **Your Results**

What do you think largely affects your grades in this course?

How relevant is your past experience of the world to this course?



To understand Physics how much do you think about your personal experience in the topics being presented?

What do you think is the main skill you have got out of this course?

### **Homework Problems**

3. Homework problems were also set. How many of these sets of problems did you complete?
4. How did you find these problems?
5. How useful were these problems to aid your learning?
6. Answers to the problem sheets were available in the Library.  
Was this enough?  
Would you be interested in answers being on the Web?

### **5.5 The Interviews**

The questions in the questionnaire were designed to enable the student to raise matters they thought were important. The follow-up interview was to probe these responses for clarification, and in some cases, to introduce new ideas for feedback from the students.

The interviews focused on several main sections of the questionnaire:

1. The problem solving strategy.
2. How well their groups worked.
3. The type of problems used in the small group sessions.
4. Pros and Cons of the small group work sessions.
5. The purpose of tutorials.

I began with general statements, reading out a relevant phrase from the student's response with a further comment "Can you elaborate on that?" or "Can you explain what you mean when you say 'The problems were too different to the usual ones?'" In this way, extra important details sometimes emerged, where the clear and 'obvious' meanings hid some further useful insights.

### ***5.6 The Analysis of the Interview Data***

Following the transcription of the interviews, it became obvious that there were some common patterns and trends to the responses. These are presented in the following two chapters.

### ***5.7 The Recorded Small Group Sessions***

Finding students willing to participate in the interviews was hard. It was even more difficult to find students willing to be recorded during small group sessions. However I did manage to record seven groups, with five of these being of high enough quality to gather data from.

Certain technical problems were overcome with the use of centrally placed multidirectional microphones. Background noise was sometimes a problem. For the last recorded session I removed the students to a quiet and secluded location. I do not think these factors influenced the activity of the groups. There may have been some general self-consciousness about being recorded, but I do not think that it was significant with the groups who allowed me to record them. What was difficult to assess was tutor involvement, as in every case this was absent, even when it was needed. The tutors tended to stay away from a group being recorded and the groups didn't ask for help.

### ***5.8 Analysis of the Recorded Small Group Sessions***

The seven small group sessions recorded in full or in part, I have labelled as Session 1 through to Session 7. They worked on one of two problems, either an exam question from a previous year, or a sledge question.

This table lists details for comparison:

Session No	Which Problem?	No of Students	Correct Solution?	Comments
1	Exam	3	Y	This session is presented in detail in Chapter Six.
2	Sledge	3	Y	Poor audio made full analysis difficult.
3	Exam	2	Y	Written records unavailable. For some reason the students did not leave them.
4	Exam	3	N	
5	Sledge	3	Y	
6	Exam	3	N	
7	Exam	3	N	Written records unavailable. For some reason the students did not leave them.

It was my original intention to present a general summary of various features from all the recordings. Instead I have focused on one particular recording only, Session 1, and have annotated a full transcript of this interaction in Chapter Eight. Session 1 is of particular interest in that it shows many of the best features of small group work. Analysis of extracts from the other recorded sessions are contained in Chapter Nine.

### **5.9 Further Data and Analysis**

Three of the five tutors completed written feedback and of these three, two gave some further verbal comments. I also completed a simple comparison of exam marks for the final exam for 1997 and for 1998. Marks from 1996 were not available in a form suitable for analysis.

## 6. The Student Interviews: Responses

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### 6.1 Introduction and Methodology

Eleven PHYS102 students completed a questionnaire on matters relating to the new style PHYS102 tutorials. As discussed in Chapter Seven, the questions covered attitudes and feelings about the problem sheets, the types of problems and the small group sessions. The complete questionnaire is reproduced in Appendix Four.

On the basis of this questionnaire, an interview was conducted that sought to probe the ideas of each student further.

Direct quotes from questionnaires and follow up interviews are reproduced at some length in section 6.2 that follows. The issues raised are complex and interconnected. For this reason a certain amount of repetition occurs.

In the analysis which follows, each student is referred to by number, with (Q) indicating a response from a questionnaire and (I) from an interview.

The actual question may occur separately like this:

*What do you think are the pros and cons with working in a small group?*

Student 3 (Q)     Pros – something different.  
                         Cons – We were assessed for it which isn't fair, as people should be tested on individual knowledge.

Or the question may be included in square brackets like this:

Student 8 (I)     [*What are some of the negatives of working as a group?*] Communication. Sometimes, one person did all the work, but they benefited and the others could learn off that.

The evaluation of the responses was not always straight forward. Consider this response from Student 4:

*Homework problems were also being set.  
How many of these sets of problems did you complete?*

Student 4 (Q)     I completed all the problems until I found out they were not going to be assessed.

*How did you find these problems?*

Challenging and relevant.

*How useful were these problems to aid your learning?*

Initially when I did them, I found that they deepened my understanding because they forced me to read, read notes or find, read and understand the relative (sic) theory.

And from another student:

- Student 9 (I)      The thing that I personally feel is that these problems were given as homework. Right at the start we all jumped in and did them. Then once we found we got no credit for them, then I personally found that I stopped doing them.  
But I find out now that it didn't help me not doing them.

We see a conflict in the minds and motivations of the student. The student recognises that the problems are worthwhile to do, and even admitting benefiting from doing them. Yet he then chooses not to do them when he found out they were not being formally assessed, and hence he was receiving no 'marks' for doing them.

The relationship between what a student perceives as useful and valuable and what a student will actually do, is not a clear-cut cause and effect relationship.

It is with these deeper issues in mind, that the statements made by these students in their interviews need to be considered. For many students, the work in these small group tutorial sessions forced them to move outside their comfort zones. Rather than being a passive recipient of knowledge and ideas, there was little option for them but to be fully involved. The tutorials put pressure on them to work. The students did not always find this pleasant. Most students probably tend to want an easy way out, and directly and indirectly, this was admitted by several of the students interviewed.

This then is a significant finding: what is best for student learning may not always be viewed favourably by them. The corollary to this is that even a small amount of course credit can have significant effects on student motivation.

## **6.2 The Small Group Experience**

The analysis starts with a general question from the questionnaire. This provided an open-ended opportunity for the student to express opinions and experiences with working in the small groups. Out of the responses to this question, other matters arise which I shall then follow up in turn. This section presents what we can learn from the student responses during the interviews.

*What do you think are the pros and cons with working in a small group?*

- Student 1 (Q)      Bouncing ideas off each other, the chance to explain to other students or have them explain to you how to do problems.  
They are down at your level, so often much easier to understand than the lecturer or even the tutor.
- Student 2 (Q)      Communication is a pro for the slowest student, it would be a good way to learn, but the quicker students would be frustrated, otherwise slower students may get left behind.
- Student 3 (Q)      Pros – Something different.  
Cons – We were assessed for it which isn't fair, as people should be tested on individual knowledge.

- |                |   |
|----------------|---|
| Student 4      | No response   |
| Student 5 (Q)  | Pro – seeing other people tackle problems.<br>Con – not everybody is interested.<br>Some go too fast. Some can't catch up.  |
| Student 5 (I)  | Well some people get in and just write their equations down. Other people make a diagram. Again other people just try and do it with their hands. "The carriage is there, and it goes over to there -"(gesturing) to see how some people tackle different problems, and when I was stuck and people showed me how they tackled the problem, that made it clearer to me. |
| Student 6 (Q)  | Pros.–Easier to obtain answers. Experience at working with others.<br>Cons–Though doing all the work yourself, some members avoid contributing. Lots of ideas. If one person gets stuck, someone else can usually carry on.   |
| Student 10 (Q) | I learnt quite a lot from this problem and having people to discuss it with.  |
| Student 11 (Q) | Pros–Other students tackle problems from different perspectives. I get ideas from them.<br>Cons–I felt I had to initiate everything as other members were more passive.   |

This view of the tutorials as provided by the students themselves, is flawed, fragmented and imperfect due to the multiple underlying motivations and attitudes from which they are speaking. However, with careful analysis it is possible to tease out issues and provide a useful evaluation of the small group process.

Overall, the students responded positively to the tutorials. However they also raised a number of issues to do with relationships within the groups, and how well the groups worked.

### **6.3 One Person Dominating a Group One Group Member who "Knows-It-All"**

There were differences of ability or stage of knowledge within the small groups. This was a constant source of tension for some students. However, they did not all view it the same way.

A common issue raised was that of a group member who 'knew it all' and tended to rush off and do his or her own thing. It did not make for a well-functioning group.

- |               |  |
|---------------|--|
| Student 3 (I) | If this was not managed, sometimes I would work with this guy who would just sit down and put down a formula and put in some numbers. He'd just leap into it but didn't confer with anybody else, because he wasn't used to working with anybody else. |
|---------------|--|

Even so, Student 8 reported that he could learn from this type of situation.:

- |               |   |
|---------------|---|
| Student 8 (I) | <i>[What are some of the negatives of working as a group?]</i> Communication. Sometimes, one person did all the work, but they benefited and the others could learn off that. |
|---------------|---|

In some cases the difference was not so much in ability but in preparedness:

Student 5 (I)      The problem was that one guy was really ahead of us in the way that he knew all the equations, while we sort of knew the basics, and tried to revise it while we were doing the problem.

Student 1 had not done any physics before and so commented “I just had to work hard”. She said that she always worked through the homework. In some of the tutorials this gave her a slight edge:

Student 1 (I)      *[Did you get a chance to explain to other people or was it always others explaining to you?]*  
I did get a chance because of the homework [that I had done]. I got a chance to explain to the guys and they said “How did you do that?”

This was a positive experience. She indicated that because it helped increase her own confidence, the difference in preparation before the tutorial was used to advantage during the tutorial. This confidence helped her during time spent on co-operative problem sheets.

A student who knew more than the others could help the group by “being able to explain how they did it”. This was seen as a positive. If he/she couldn’t explain something being put forward, then that was a negative:

Student 1 (I)      . . . we had one guy in our group who knew it all – in fact he didn’t in spots – and he couldn’t even explain to us how he did it.

Hence the issue of who does the work and in what way they do the work, is a contributing factor to the perceived success of a group.

In the perception of some students it was better to have a group where everybody was about the same:

*What factors actually make a small group work well?*

Student 5 (Q)      Everybody should have about the same knowledge.

Student 2 (Q)      Everybody of similar ability.

Student 7 (Q)      No one person dominating and doing it largely on their own.  
Also, everybody being of approximately equal ability.

In these responses, two key factors are relevant. Firstly, the relative ability of group members, secondly, the group dynamics and the quality of the interaction.

If there are students with more ability than others in the group, then how the relationships between them and the group operate largely determines the success or otherwise of the group work in assisting learning of the less able students. If student with more ability takes time to pause briefly while others think, or tries to explain clearly, then two benefits emerge. The student who explains strengthens his/her understanding, and the others benefit as well.

This is clearly shown in the recorded small group Session 5. Gentle and persistent questioning by a weaker member of the group exposes a weakness in the assumptions by the student taking the lead. (This is referred to in more detail in Chapter Nine.) Heller et al (1992b) confirm this observation:

The best problem solver in each group usually provided the leadership in generating approaches to the problem, the medium and lower ability students often provided the monitoring and checking to make sure that conceptual and procedural mistakes were not made. . . .(p634)

#### **6.4 Benefits of Working With Others**

There were a variety of responses where students reported that they valued and appreciated the opportunity to work with others. The main reason was just so that students could learn off each other. At a basic level this was just seen as simply ‘getting the answers’:

*What do you think are the pros and cons of working together as a small group?*

Student 6(Q)     Pro – easier to obtain answers. Experience working with others.

Student 10 (Q)   Pro – if I don’t understand how to do problem, I can learn from the people around me.

Student 10 (I)     I can check all the time.

At a deeper level however, some students commented on the value of seeing *how* other people do things:

Student 5 (Q)     Pro – Seeing other people tackle problems.

Student 5 (I)     Well some people get in and just write their equations down. Other people make a diagram. Again other people just try and do it with their hands. “The carriage is there, and it goes over to there -..” (gesturing) to see how some people tackle different problems, and when I was stuck and people showed me how they tackled the problem, that made it clearer to me.

Student 10 (Q)   I learnt quite a lot from this problem and having people to discuss it with.

Student 6 (Q)     By working in a group I felt that I learned a lot about different ways of approaching problems – ones I wouldn’t have thought of.

Student 1 (I)     I have to say you’ll see it, and we had a couple of very bright guys, and they explained to me how they did it, and that is how I learned it.

With Student 7 there was recognition of the benefits of teamwork even though he states it does not suit him as he prefers to work alone:

Student 7 (Q)     [*What are the pros and cons of small group work?*]  
That develops teamwork skills, and people learn from each other’s ideas. One disadvantage for me, is I find I learn better working on my own, so value for time may not be as high.

Different perspectives were appreciated:



Student 11 (Q) Pros – other students tackle problems from different perspectives.  
I get ideas from them.

Student 8 (Q) Pros – diversity of ideas.

There is also recognition of the benefits of being able to explain things to others:

Student 8 (I) I learned a lot in explaining ideas in the group.  
One guy didn't really have a clue, and we had to talk quite a bit before he really understood.

With one exception (Student 7 (Q) from above), all students were positive about “being together and learning from each other”. This included those students who expressed concern about others dominating the group (e.g. Students 5, 1 and 3 for example, quoted above).

Heller et al (1992b) suggest that there are advantages in being together with others of different ability:

In heterogeneous groups, the low or medium ability student also frequently asked for clarification of the physics concept or procedure under discussion. While explaining or elaborating, the higher ability student often recognised a mistake, such as overlooking a contributing variable or making the problem more complicated than necessary. (p634)

Considering the case of several brighter students working together, Heller and Hollabaugh (1992a) comment:

Most of the homogeneous high-ability groups ... tended to make problems more complicated than necessary or overlooked the obvious. They were usually able to correct their mistake, but only after carrying the inefficient or incorrect solution further than necessary. (p641)

This was observed in recorded small group Session 6, which didn't manage to correct their mistake and yet had several above average students in it. (See Chapter Nine for a fuller comment on this)

## **6.5 Second Teaching and Street Language**

Many of the comments above are a reflection of what has been called ‘second teaching’ (Gatreau and Novemsky 1997) which often takes place *following* formal instruction. In this so called second teaching, student-student interaction is often in a semi-formal hybrid language quite different from the formal language of the teacher. This is clearly illustrated in the dialogues analysed in Chapters Eight and Nine.

There is also the acknowledgement that students explaining to students can have a good effect:

Student 1 (Q) Bouncing ideas off each other, the chance to explain to other students or have them explain to you how to do problems.  
They are down at your level, so often much easier to understand than the lecturer or even the tutor.

The style of communication the student is referring to here and which is “often much easier to understand”, has been referred to as the ‘street language’ of physics which is quite different to the formal language of the lecturer or tutor (Gatreau and Novemsky 1997). In this context it is an informal way representing physics ideas in terms of the prevalent student culture, slang and colloquial terms mixed in with physics terms and ideas as well. Vygotsky suggests this is a significant and important stage in developing conceptual understanding. It represents an important intermediate stage in learning concepts.

For an example, consider some extracts from recorded Session 6:

- G1:                   – so we know that  $T \cos \theta$  equals the force in that horizontal direction which equals the force so we know the force equals *ma*. ??  
[Pause –]
- G2:                   Because *ma* doesn’t equal zero, but  $T \cos \theta$  equals minus that minus that.  
[pointing to work on paper . .]
- M:                   – but yet, you just move it over.

Commenting on the underlined sections, “you just move it over” is a description of a legitimate activity with vectors in a colloquial form. “Because *ma* doesn’t equal zero” is also using *ma* as common student jargon to refer to the resultant force.

In the next few examples extracted from recorded Session 1 (using A, B and C to identify each group member) the students are using their own version of the formal physics terminology of lectures and textbooks. These are of common words being used in a non-standard way:

- |   |   |   |   |
|---|---|---|---|
| A | <p>eah, the normal force is just reaction off the surface.<br/>Any other force doesn’t get <u>included</u> in the normal eh?</p>    | Y | <p>“Included” not standard terminology.</p>     |
| B | <p>- just c</p>   |   | <p>“Detracted” is not standard terminology.</p> |
| A | <p>Here it's got the normal force <u>helping</u> it.<br/>Here you have to help it.<br/>You can still feel a strain on yourself.</p> |   | <p>“Helping” ditto.</p>                         |

These are common English words applied in a new way to the notion of forces. They are NOT wrong usages. They communicate, and are useful in the development of concepts.

The next example is a physics term used wrongly:

B

The 40 “Newton” is the unit for force not work. The correct term is “Joules of work”.

However, while there was a lot of dialogue without units – there was very little actually *wrong* or with *wrong units*.

On the other hand there are statements which are clearly quotes from physics jargon:

A

But if it's still on the ground the forces must sum to zero, which means our assumption may be out.

Vygotsky in his writing claimed the correct use of formal terminology was learned through modelling and assimilation. The ‘sage on the stage’ uses these terms and phrases in formal instruction and students to one degree or another, and with varying degrees of precision, absorb the ideas.

Another way that students pick up things is in a kind of ‘physics shorthand’ – using the statement of equations to try to encapsulate what they are doing or thinking about. In the same dialogue, Student A constantly seems to talk to himself in this fashion.

## 6.6 Keeping Up With Homework

Another issue raised by many students is that although the students recognise the value to them of prior study for the tutorials, they were usually not sufficiently motivated to actually do any. Student 1 reflects in her comments on the benefits of proper preparation:

*Did you ever get a chance to explain to other people, or was it just other people explaining to you?*

Student 1 (I) I did get a chance because of the homework. [Which she said she always did] I got a chance to explain to the guys, and they said “How did you do that?”

The student also commented:

Student 1 (I) I did the readings every day at the right time, and I managed to do the homework. It was a great way to make sure I was on the right track, - I had done it the right way. Even though I wouldn't have every single question right.

This student shows a large measure of maturity in her orientation to the course, the work and tutorials. It does remain a question about how much this attitude can be taught or modelled to the students.

## 6.7 The Style of the Tutorial Problems

As discussed in Chapter Five, part of the questionnaire sought to probe student responses to the special type of problem that were used in the small group work. These problems were very different to traditional type problems. In fact they were different to the type of problem involved in the final exam. They were explicitly designed for small group work and for *developing* the concepts required, and were not intended for personal (individual) practice or assessment. For two sample problems, see Appendix Four in the student questionnaire.

Student 5 (I)     *[How did you find the problems from the tutorials?]*  
It's hard getting used to it at first. When you have done one or two you get into it more.

Most students enjoyed the problems.

Student 2 (Q)     The type of problems were good.

Student 6 (Q)     Sometimes (the problems were) a bit easy, didn't require too much lateral thinking.

Our group worked fairly well at these problems, but often were short of time and did not finish.

These problems were worth while and I learned a small amount although I found a level of difficulty not much higher than bursary physics.

Student 8 (Q)     *[The problems were good in that . . .]* they were specifically chosen to highlight a particular piece of work.

Student 9 (I)     The problems that were given were good.

Student 7 (Q)     I found the problems to be very good, they tested a variety of problem solving skills and concepts.

There was divergent opinion on the relevance to the course:

Student 2 (Q)     They were reasonably topical to what we were studying at the time.

Student 3 (Q)     They weren't related to the course being taught in lectures.

The contexts of the problems was appreciated by some . . .

Student 1 (Q)     I found them a nice wee story to go around the problem makes it more interesting, and also more realistic.

Student 5 (Q)     *[The problems were . . .]* Good, because funny, and not dry but applicative.

But on the other hand, not appreciated by others:

Student 3 (Q)     The Lone Ranger problem had lots of important concepts that would be better addressed with conventional problems.

The negative statements above tended to come from Student 3. This is possibly a reflection of his learning style. Later on in his interview he reported that he found it difficult to work back from problems to understand concepts and:

Student 3: Usually what you end up doing is looking up sample problems, and copying out the method they use, rather than figuring out how to do it by yourself.

It is clear from research on student problem solving that the approach of Student 3 does not work, for example see Van Heuvelen's work (1991) on student problem solving methods. His findings suggest that a problem solving methodology needed to be carefully developed and explicitly modelled if students were to make progress beyond a random search methodology of trying to match numbers with formulas. However, several comments indicated that a search for the formula was foremost in the mind of more than one student. For example:

Student 3 (Q) Sometimes I would work with a guy who would just put down a formula and put in some numbers . . .

Student 5 (Q) [*The problems . . .*] made the use of the formulae clearer.

Even though a formal problem solving strategy was provided in tutorials, there was little evidence that it, or any other sound strategy, was consistently used by students. In general the students were dismissive of the problem solving strategy as it was presented. (See Appendix Three.)

Student 1: (Q) The theory was good but it didn't work in practice.

Student 2: (Q) We found it harder to keep to the problem solving strategy than to do the actual problems set.

Student 3: (Q) Not very.

Student 4: (Q) Not very useful.

Student 5: (Q) Theoretically yes, but we didn't get any feedback if we followed it correctly.

Student 8: (Q) Restrictive.

The general attitude of the students in the interviews was that they wanted to "just get on with the problem solving". The students did not say this specifically, but I surmise that we failed to show the need or the relevance of the strategy we provided. A response to this may be to adopt a much more collaborative approach to the development of a strategy where students are involved in the process. There are various ways this could be accomplished, the simplest being to spend time with a completed solution and in small groups devise their own strategy from it.

A few commented on the lack of time. Maybe the time pressure encouraged students to "get the answer/formula" rather than think through the problem. Here is what Student 9 reported:

Student 2 (Q) The problems were often too easy for some, and not for others. We managed to solve most of the problems, but sometimes we went out of time.

Student 9 (I) [*How did you find the small group sessions?*]  
I think it depends whether you understand what you are doing.

Trying to achieve what the objective of being together is.  
I found that I was out of place most of the time. Coming here as an adult student I found it was really hard, and at times I didn't understand what was going on.  
I found I didn't get enough time to go through and absorb what we were trying to do.

There are other issues here. Further questioning showed that this particular student probably missed out on some help because he was not familiar with the way the university course worked. The tutorials were not really a factor in this.

This lack of time was not a worry with Student 7 who concentrated on the process rather than the answer:

Student 7 (Q) *[How successful you thought you were?]*  
Successful, except we ran out of time to complete them. Usually by the end we had planned and we executed the solutions so were confident we would have reached the correct answer, had we had time.

There were those students who indicated they liked 'challenging problems':

Student 2 (Q) *[What factors actually make a small group work well?]*  
Everybody at a similar ability, personalities mix nicely, challenging problems, humorous problems.

One student indicated that some of the problems were hard:

Student 1 (Q) *[How did you find the type of problems set in tutorials?]*  
A couple of them were too hard, and we were stumped right away which wasn't very helpful.

No-one made any general comment to suggest that *overall* the problems were too hard. There were groups that could not make progress on some of the problems, but their ways of coping or not coping with their difficulties are a separate issue which is considered in Chapter Seven.

## **6.8 The Management of Group Work**

A thread on the nature of group work, and the motivation of individuals was unravelled when Student 1 made specific comment on the problem sheets.

*You have commented that you think the sheets are time wasters?  
Can you explain why this is?*

Student 1 (I) Well, the Tarzan and Jane one – we sat there for about 20 minutes talking about the weather, and we could have gone through quite a lot of the problem in 20 minutes because we only have 1 hr of contact time in the week.

*So the tutor didn't give you a kick start of anything?*

No.

*Can you remember if you asked for help and didn't get it,*

Oh no. We wouldn't have asked – to be honest with you.

This is partly a management problem, which could have been helped by a tutor intervention. It is also an attitudinal problem of the individuals in the group. It is a sobering statement to say a group (or an individual) just “wouldn't have asked” for help.

Further on in the same interview, when further questioned, she had this to say:

*So you would rate not so highly with interaction. [being forced on you in a small group]  
You would rather have it [the interaction] only when you wanted to?*

Student 1 (I) I would rate it very highly – but people would sit by themselves instead of being put there and have to interact.  
It depends a lot on people. My first tutorial was shocking, people don't talk to each other at all. We'd try and say – this, but there is nothing you can do with people like that.  
The next tutorial was totally the opposite.

Student 1 actually changed tutorials, and as she states the two tutorials were very different. What factors cause this?

This could be partly a problem with the prevailing culture, the motivations and attitudes of the students as a whole population and the tutorial groups in particular.

Some of the students interviewed commented explicitly that the group work in the tutorials got better as they went on. This was attributed to two main factors.

Student 3 (Q) *[What factors make a small group actually work well?]*  
Knowing the people in the group properly. This can only be done with time.

Student 3 (I) *[How useful did you find the problem solving strategy?]*  
Not very – because people didn't know each other.  
When you walk in and do a physics tute and everything is new, University is new, you don't know anybody in the class, so people can't work together in small groups that don't know each other.

*[How long do you reckon it takes to know each other?]*  
By the end of the term, we still didn't know each other even though people will naturally sit at the same spot in tutorial class.  
And so we all work in the same groups. Even so, at the end of the course, we still mightn't know everybody's name in the group.

Student 8 (Q) Grouping helped later on in the course, but wasn't too beneficial at the start as no one seemed keen to discuss the problem. Shyness most probably.

The students here are suggesting that knowing each other better helps groups function better so (naturally) groups will work better later on in a course.

The other factor suggested was being more familiar with the concepts of physics as a reason why things worked better later in the course:

Student 4 (I)      Towards the end – there were just three of us – there was a group problem – and we just roared though it.

*What made this successful?*

Maybe we were more at ease with the concepts.

One factor of significance was not mentioned, not even hinted at, in any of the interviews. I would have expected a growth in small group skills to occur during the course. Nobody mentioned this, not even in passing. Whether there was improvement in small group skills, or not, I cannot be sure. What I can say is that observations during the tutorials on an ad hoc basis showed people much more focused towards the end. Tutors report this as well. But the factor that could have contributed to this may equally well be the closeness of the exams.

I surmise that the small group ethos was still not well established at all either in the expectations of the tutors or the students.

An omission from the questionnaire was a specific probing of the group roles. However, several students mentioned them during the interviews, none of the comments being very supportive. The success of an allocation of roles on a group from outside by the tutor depends largely on the dynamic between the tutor and the groups. The tutor training to help develop skills to do this was sparse, partly due to a lack of confidence in how these would go. I suggest in Chapter Nine that certain roles are vital for groups to function adequately. As with the problem solving strategy, the interview feedback suggests our presentation of these roles was inadequate. An interactive approach to develop an understanding of group-work would be likely to meet with more acceptance.



## 7. Student Interactions in Small Groups

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In the model of learning in physics outlined in chapter three (section 3.2), point 4 stated:

4. Individuals show a significant variation in their style of learning along a number of dimensions. (Redish 1996b)

From the analysis in chapter six we see that students show a range of preferences in respect to small group work and their attitudes vary significantly. This chapter looks at matters to do with interactions within the small group and considers possible responses to improve the quality of the small group work.

### 7.1 Struggles in the small groups

There were two major issues that students struggled with. The first was if a group did not function well and the second was if a problem was too hard. These two matters are interrelated, but how students actually perceived these issues was not straightforward.

Student 3 was fairly critical of the way small groups worked in his tutorial. Yet, at the same time, while being critical of others not working, and of having to do most of the work himself, he also commented that he personally benefited from the experience of being able to explain the work to others. On one hand he disliked the group, and on the other hand, he described some benefit from the experience. As is so often true, growth and development of concepts is accompanied by hard work. Some students recognise this and commented on it positively, others recognised it and commented on it negatively.

Repeating a quote from the previous chapter:

Student 4 (I)      Towards the end – there were just three of us – there was a group problem – and we just roared though it.

*What made this successful?*

Student 4          Maybe we were more at ease with the concepts.

This is a very interesting linkage of ideas. This student, Student 4, had earlier on in his questionnaire linked the success of a group with familiarity with one another.

*What factors make a small group actually work well?*

Student 4 (Q)      Familiarity and acceptance of each other. Taking on roles that you are comfortable with or are prepared to do because others are not.

But he also shows an awareness of the ideas and concepts involved with the problems.

Further examination of the interviews as a whole, with the exception of Student 4, shows a consistent preference. Some students seemed to fit more comfortably into a group role if they were familiar with the problem. Others were more relaxed and happy when they knew others in the group.

It appears that for some students, if they are relating well together or are familiar with one another, it doesn't matter if the problems get a little hard. It is just a matter of having a good time and being together as you work. From the other point of view, if a student is familiar with the concepts, even if the problem is difficult, it doesn't matter if there is a lack of familiarity with the others, because progress can still be made on the problem.

Students were able to get something out of a session if the group functioned well or if the work on the problem proceeded satisfactorily. But if the group did not gel and also struggled with the problem, the students felt under real pressure and were not comfortable.

### ***7.1.1 What happens when a group doesn't work***

When things did not go well in a group, there was a range of responses from the students involved. Some students were active in trying to help the groups function better, others were quite passive or wanted the tutors to become involved.

Student 8 seemed a little more pro-active than average from his interview. He commented:

Student 8(I)      It just didn't work at the start – we didn't know each other and I would try and get things going but I wouldn't get much reply  
People were I think just shy  
It was a lot better later on in the course when we knew each other, I would come in early to the tutorial room and just talk to the person next to me.

This student actively sought to build relationships with others in his tutorial. Another comment on initiation.

Student 11 (I)    I felt I had to initiate everything as the other members were all passive.

Student 11 (Q)   Other students tackle problems from different perspectives and therefore I can get ideas from them.

Student 11 was very aware of having only a limited background in physics. She perceived others in her group as being "better at it than her". Her response was to be more active in trying to make the group work, which is in contrast to the attitude of other students who were often quite passive and gave up.

These problems to do with social interaction are real, but not insurmountable. Experience in other courses indicates there are some strategies which can help, generally involving some form of tutor intervention. (Heller et al 1992b) Students then need two things: some positive experiences of small group work where things have gone well, and the understanding to put things in perspective when groups face problems. Metacommunication is required: communication about communication, communicating about the process the students are part of in the small groups.

### 7.1.2 What happens when the problems are too hard?

This is a more complex question. The problems are supposed to be challenging, located in the zone of proximal development, that is, problems that are too hard for individuals on their own, but not too hard for the combined effort of the group.

Some students tried to take initiative. In the recorded sessions this sometimes took the form of searching through notes. In none of the recorded sessions did they ask for help from other groups or the tutor, probably because they thought that since they were being recorded they should not do so. This illustrates one of the problems in gathering accurate data: making observations through recording the groups can have some effect on the working of the group and alter what is being observed.

In the transcript of session 2 there is some commentary obviously aimed at me as the observer:

Student N:            Looking at our answer we have decided that for one person to accelerate that mass to 86.4 m per sec is extremely unreasonable so we had a look at a formula book and we discovered that the formula we used  $v_f$  equals  $v_i$  plus at squared was actually wrong . . .

Referring to text books was often the activity if there was a specific difficulty with the question – if the students did take some initiative:

Student 1 (I)        Well, the Tarzan and Jane one – we sat there for about 20 minutes talking about the weather, and we could have gone through quite a lot of the problem in 20 minutes because we only have 1 hr of contact time in the week.

*So the tutor didn't give you a kick start or anything?*

No.

*Can you remember if you asked for help and didn't get it,*

Oh no. We wouldn't have asked – to be honest with you.

I could find not evidence of students referring to the problem solving strategy when they encountered difficulties. There was clear evidence of improvement in some of the sessions where the problem sheet forced students to work through the problem solving steps, especially in the first assessed problem, which was collected in and formally marked.

## 7.2 Resolving Problems in the small groups

The students who consented to interviews all showed evidence of some degree of initiative. They had a positive and proactive attitude.

Student 3 commented:

Student 3 (I)        I did the work and maybe another person would help sometimes. Most of the time I would end up doing everything, doing all the work and then I had to go and check with each person to make sure that everybody else understood.

I always had to do that and I would walk everybody through the problems, basically do the whole thing by myself.

And from Student 9:

Student 9 (I) I found one or two in our group would just sit back and say – “I don’t know - I can’t understand it”, and they wouldn’t do anything. They wouldn’t get involved. They wouldn’t do it. That was on the negative side to it. Some were not willing to get involved and participate in group discussions.

The picture we gain here indicates that there are other students who are passive and less active, at least in the perspective given by those students being interviewed. Ability and confidence considerations do come in here. A student of higher natural ability may not need too much confidence to make a contribution. However with some confidence and in a supportive environment even students who did not see themselves as strong in this subject were able to make a good contribution and through this they themselves can improve their skills and further build their confidence.

There were a range of ideas on why groups didn’t work.

Student 3 commented at length:

Student 3 (I) To know people properly, you need to spend time with them, and in terms of the context, you do need to know them. I suppose if you are an outgoing person, or if you are in a group one or two shy people who don’t talk much at all. Then it’s very hard. So then again, it depends on the type of people in your group. Someone who is very energetic and stuff. They might feel that group might come together quite quickly.

*What affected how well the group worked?*

Student 8 (Q) It was largely dependent on the peer familiarity, how outgoing people were, so not very well.

Student 8 (Q) Grouping helped later on in the course, but wasn’t too beneficial at the start, as no one seemed keen to discuss the problem. Shyness most probably.

Further suggestion from Student 8, was to start the small groups in twos. “It would be easier to work in small groups with one other person.” (I) She suggested we keep the bigger groups until half to two thirds of the way through the course.

Some students were more focussed on getting the right answer, no matter how this was gained or whether they had any understanding of the concepts involved. Others were more interested in appreciating the process. Tutor feedback and informal observation indicated that this focus changed a little as the term progressed and examinations became imminent. But what is of concern is the number of students, who on day one have a primary focus on just the answers, getting things right, and who rarely take time to ponder on the ideas and concepts behind them.

These kinds of statements reflect more of a concern with the answers:

- Student 6 (Q) I thought we were successful because we obtained answers to the questions that we thought were correct.
- Student 2 (Q) The problems were often too easy for some, and not for others.  
We managed to solve most of the problems, but sometimes we went out of time.

Others show a slightly broader perspective:

- Student 1 (I) You should look more at the concepts as well. It is the most important thing – the questions of the exam paper at the end of the day – isn't it?
- Student 1 (I) Actually I found it very social and really enjoyed my physics tutorials. It had got such great people on it.  
Actually, I think it is very important rather than coming in here and just being a sponge.

Student 7 focussed on the method far more explicitly than the others, and was positive about the process. He was quite explicit several times that the problem solving strategy, the process and the gaining of understanding, featured quite significantly for him:

- Student 7 (Q) [*How successful did you think you were?*]  
Successful, except we ran out of time to complete them. Usually by the end we had planned and we executed the solutions so were confident we would have reached the correct answer had we had time.

Student 10 commented:

*How successful do you think you were?*

- Student 10 (Q) Very successful at learning. Perhaps not so successful at obtaining the correct answer using the correct method.

It is good that he felt he was learning. What he means by 'the correct method' however is unclear, possibly a reference to our given problem solving strategy.

Sometimes the keys to resolving problems in small groups lies within the group. Students will emerge who are able to take leadership or make comments to help a group get past a roadblock in the solving of a problem. Sometimes merely having a critical mass of students with a positive attitude and some broader understanding is all that has been required. Bringing about this kind of environment in the tutorials and developing student skills in groupwork is essential.

### **7.3 Developing student skills in groupwork**

As discussed in the preceding sections, there are indications in the interviews that students are aware of group dynamics and are sensitive to some of the roadblocks to learning in small groups.

Generally however, their expressions and understanding are fragmentary, and my impression is that for many it would not take much to develop a more comprehensive

and robust framework for appreciating the role of groupwork in the learning process. At the commencement of the course, I spoke for a few minutes to each of the two lecture streams to outline what they could expect in their tutorials where group work was concerned. They were also given a handout sheet (see the Appendices) and I invited any students who wished to, to come and see me. Students were also given written handouts in the tutorials on aspects of groupwork (see the appendices).

Even this small amount of orientation to the students as a whole seemed to have some positive effect on helping students understand more about the learning process. Some of the individual talks I had with students and others reported by the tutors support this view.

About 20 students came to see me for various reasons. Some were interested in making their opinions known and giving feedback on their perceptions of the tutorials. Some of these students later consented to be interviewed or participated in a recorded small group session.

Among the students I talked to, there were several who were questioning the value of the new tutorials. They were quite open to discussing the issues. With these students, I spent some time discussing what I had been reading about advantages of learning in groups and the importance of at least some of the coursework being presented in this way. In each case these were first year students and we discussed the difference between high school and university classes, how we learn 'best' and what is 'real learning' rather than 'rote learning'. After discussion, all these students went away indicating a receptivity to these ideas.

This was an informal self-selected group of students, having more initiative than average, and probably also more reflective on their own learning than is usual. It could be argued that they would achieve well in any setting because of these attributes. What I would suggest is that many more students could benefit from this kind of interaction where the activities and styles of learning are put under scrutiny and the questions are asked "How do I naturally approach this kind of learning activity?" and "What is the best way for me to do it - even if this better way is not my natural inclination?"

It is possible that students could also be helped by some understanding of their own preferences in the way they learn, an idea that has come to be referred to as a "learning style". To set this in context, the next section is a digression to provide some background.

### **7.3.1 Learning Style: Background Perspectives.**

Over the past twenty years, there has been a growth of interest in the study of what has come to be called "learning styles".

There are many threads to this approach. One of the major influences has been the work of Rita and Ken Dunn. Since the mid 1970's, their work at the *Institute for Learning Styles* has been influential in many parts of the world through a programme of seminars and various resources that they have produced based on their work. Following

on from this, many other new initiatives have been developed providing practical classroom based applications and resources using learning styles. Their current philosophical basis for their work includes these statements:

1. Each person is unique, can learn, and has an individual learning style.
2. Learning style is a complex construct for which a comprehensive understanding is evolving.
3. Individual learning styles should be acknowledged and respected.
4. Learning style is a function of heredity and experience, including strengths and limitations, and develops individually over the life span.

Rita and Ken Dunn (Learning Styles Network) <http://www.learningstyles.net/n7.html>

This is a fairly representative statement of a philosophical view on learning styles common to many educational institutions all over the world, including schools and teacher training organisations.

There is debate about the nature of these so called “learning styles”. One view is that learning styles are innate, that they do exist and exert a moderating and sometimes controlling effect on the preferences of students. Another view is that the evidence does not support the existence of innate preferences. Such observations as are included in research evidence for the existence of styles of learning are attributed to mere *habits* developed in students. Such habits are seen as being the result of conditioning or experiences of the individual and are not seen as being innate.

The usual process of developing a theory of learning styles is to develop a taxonomy based on a series of observations leading to a classification of learning styles. An assessment tool is developed forcing participants to make choices between phrases or descriptions, and dependent on the choices made, a profile is developed which is linked to certain characteristics of how a person learns. The final formulation is usually seen as a dynamic description, a helpful indicator to the student and teacher, rather than a prescriptive straight jacket.

Most of the research work in learning styles and its application in teaching has been carried out with students in liberal arts courses. I can find no significant projects in university or high school physics courses beyond the small scale effort and interest of a single lecturer in a single physics department. However there are some initiatives in the wider field of science and technology in general. As the need for improved teamwork skills has grown, several major long term studies have taken place in both technology education and in engineering. One such project is Richard Felders work with a cluster of engineering departments including a major longitudinal study at the Department of Chemical Engineering, North Carolina State University which commenced in 1990 (Felder 1998).

Felder’s approach to educational theory is similar to that described in chapter three in the development of a model for teaching physics. He draws on various ideas and concepts in educational theory but the final formulation is quite pragmatic. He has taken a range of learning style and personality type theories and compiled his own model of learning styles (The Feldman-Silverman Learning Style Model) which he uses

alongside several others principally the Myers-Briggs Type Indicator (MBTI). These are described briefly below.

A statement of his definition of a learning style includes this:

Students have different *learning styles*--characteristic strengths and preferences in the ways they take in and process information.

Richard M Felder (Felder 1996)

<http://www2.ncsu.edu/unity/lockers/users/f/felder/public/Papers/LS-Prism.htm>

Following on from his work, a number of other engineering departments in the United States have carried out some systematic long term studies involving an evaluation of students, faculty, student achievement and courses from a learning styles perspective (Felder 1996). There are four different models that have been used in these particular engineering classes. These are listed in the table below.

#### **The Myers-Briggs Type Indicator (MBTI)**

This model classifies students according to their preferences on scales derived from psychologist Carl Jung's theory of psychological types.

M.H. McCaulley, G.P. Macdaid, and J.G. Granade. "ASEE-MBTI Engineering Consortium: Report of the First Five Years." Presented at the 1985 ASEE Annual Conference, June 1985. [Quoted from Felder 1996]

#### **Kolb's Learning Style Model**

This model classifies students as having a preference for 1) *concrete experience* or *abstract conceptualization* (how they take information in), and 2) *active experimentation* or *reflective observation* (how they internalise information).

J.N. Harb, S.O. Durrant, and R.E. Terry. "Use of the Kolb Learning Cycle and the 4MAT System in Engineering Education." *J. Engr. Education*, 82(2), 70-77 (1993). [Quoted from Felder 1996]

#### **Herrmann Brain Dominance Instrument (HBDI)**

This method classifies students in terms of their relative preferences for thinking in four different modes based on the task-specialized functioning of the physical brain.

M. Lumsdaine and E. Lumsdaine. "Thinking Preferences of Engineering Students: Implications for Curriculum Restructuring." *J. Engr. Education*, 84(2), 193-204 (1995). [Quoted from Felder 1996]

#### **Felder-Silverman Learning Style Model**

This model classifies students as:

- *sensing learners* (concrete, practical, oriented toward facts and procedures) or *intuitive learners* (conceptual, innovative, oriented toward theories and meanings);
- *visual learners* (prefer visual representations of presented material--pictures, diagrams, flow charts) or *verbal learners* (prefer written and spoken explanations);
- *inductive learners* (prefer presentations that proceed from the specific to the general) or *deductive learners* (prefer presentations that go from the general to the specific);
- *active learners* (learn by trying things out, working with others) or *reflective learners* (learn by thinking things through, working alone);



- *sequential learners* (linear, orderly, learn in small incremental steps) or *global learners* (holistic, systems thinkers, learn in large leaps).

R.M. Felder, "Reaching the Second Tier: Learning and Teaching Styles in College Science Education," *J. Coll. Sci. Teaching*, 23(5), 286--290 (1993).

Felder reports that whatever model has been used with a course, there has been positive results both in student achievement and feedback from students themselves. The models have been implemented and applied in different ways, in different situations and to different degrees.

In a whole course approach some specific teaching to a lecture group of students provides a background model and rationale to the learning styles approach and can be followed with an opportunity for all or some students to evaluate their own personal learning style. They then have these extra frameworks to think about their own learning activities.

An alternative has been to use the learning style questionnaire only when a student has specific problems. As an example, students who tend to work in a detailed and step by step fashion can be penalised unwittingly in some problem solving activities. The reverse is also true. Students at times may be best to memorise certain procedures and use these where their natural inclinations are to want to fill in all the detail and derivation for each problem. Understanding of different approaches to problem solving from a learning style perspective can help a student pinpoint problem issues and adapt their style to the specific need of the problem in hand (Felder 1996).

What has also emerged from these studies in particular, is the key role of collaborative group work in broadening and strengthening the abilities of students to develop their skills in a subject as well as developing their skills as learners. (Felder 1993)

### **7.3.2 Learning Styles and PHYS102**

In the 1998 trials with PHYS102, there was no effort to evaluate the course in terms of its instructional modes to see how it relates to various learning styles, nor has there been any effort to survey students as to their learning style. This is a useful avenue of further investigation. As has been commented, the students interviewed were a self selected group, possibly with a little more motivation and initiative than is normal. Even allowing for this, their attitude and openness to discussing aspects of their learning and possible ways to improve it does suggest that students are open to further discussion and teaching from a low key and conservative learning styles perspective which could add another useful tool to help students with their learning.

### **7.4 Summary:**

It could be argued that it is obvious that 'talking things over with others helps us learn better'. Certainly we may think that less able students may be able to learn in this way since they will have the chance to learn from others. What is not obvious is that 'working with others in small groups can help even more able students' – in the

opportunities they get to explain ideas to others. Yet this is the finding of many research projects on small groups: *all* students benefit in well structured small groups even in groups containing individuals of mixed ability.

Our findings with the PHYS102 students strongly suggest that so called average or below average students can benefit particularly, but that that specific help is needed to establish the environment for this to occur.

The feedback from the students does indicate that they appreciate being able to learn from others and at times to have the chance to explain to others. They *do* feel the benefit of interaction. Is it important for students to feel this way? The answer is yes, it does matter: if students feel good about what they are involved in they will learn more effectively. Research does support this conclusion, for example, see Johnson and Johnson (1993) for a summary of various results.

But there is also the down side to small group work. The groups don't always work, as there is ample evidence in the student responses - and even the best groups still strike hard times as the recorded sessions showed. Communication with students and helping them develop skills and understanding can help significantly. As has been stated above, this is where the role of the tutor is critical.

There are many published research papers providing convincing data to back up these assertions. However, the efforts to implement a new style of tutorial foundered on some key points, and it is less clear that in 1998 the PHYS102 tutors, or the bulk of the PHYS102 students, were persuaded. Even so, the results were good. With a better implementation of the same ideas the results could become excellent.

## 8. Thirteen Crucial Minutes in the Life of Three PHYS102 Students

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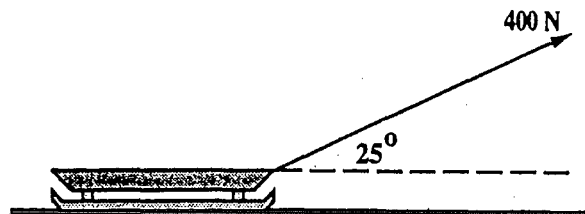
### 8.1 Introduction

This chapter presents the dialogue from one of the seven recorded small group problem solving sessions. The interactions in this dialogue contain many features that contribute to real conceptual change in the students involved. Both the internal mental activities of the individuals *and* the group interaction have been necessary in bringing this change about.

The recording took place on the second to last tutorial of the thirteen weeks. I visited all four tutorials on at that time, and there were no students willing to do a recorded session. A few minutes later, a tutor arrived at my office to say that three students had changed their mind and would do the recording. I set up the gear in a quiet place near the tutorial room and left the students to it. As part of a compromise (having discovered most students were in exam-focused mode), the problem I set was directly out of a previous year's final examination. While it is not totally typical of the context rich problems I had been setting during previous tutorials, it contains several of the key features.

Here is the problem:

2. A husky dog team in the Antarctic is pulling with a force of 400 N a supply sledge of total mass 136 kg. The pulling rope maintains an angle of  $25^\circ$  to the horizontal and the coefficient of sliding friction between the sledge and snow surface is 0.27.



- (a) What is the normal reaction of the surface on the sledge and the frictional force acting on the sledge? (4 marks)
- (b) What then is the acceleration of the sledge? (4 marks)
- (c) If the sledge starts from rest, what will be its speed after being pulled for 5 m? What then is the kinetic energy of the sledge? (3 marks)
- (d) How much work is done by the dog team in moving the sledge 5 m? (3 marks)
- (e) Compare the values of the work done by the dog team (part (d)) with the kinetic energy of the sledge (part (c)): account for any difference. (3 marks)

There are no 'tricks' in this question. It requires a clear idea of the "vector nature" of forces. Solution of the problem is facilitated by using certain conceptual tools which had been presented in lectures, in the text, and in earlier tutorial problems. The most significant of these was the *Free Body Diagram*, a special pictorial representation of the problem. It is interesting to note that the students do not use this at all, in spite of the fact that it was heavily promoted in every part of the course during this topic.

## **8.2 An Overview of the Dialogue**

The students commenced work on the problem, accompanying their work with much discussion about the way to proceed. For the first ten or so minutes, the students were actively working on parts (a), (b) and (c) based on an initial wrong assumption about the normal force involved. This error was carried on through their work and calculations until they began to work on Part (d).

All three of the students were actively involved. While one student was recording, the other students were checking calculations and actively reflecting on the work in progress. One student in particular adopted the role of criticiser, or monitor of the progress. At times, the discussion proceeded with reference to a diagram and the interaction consisted of a large number of incomplete sentences with answers, often left hanging, sometimes three different voices contributing to the same sentence. At regular intervals, clear comment was passed on the progress of their answer. Some of the debate referred to the use of a calculator as a model of the sledge referred to in the problem.

Their progress on the problem is reasonably linear until the work is well advanced and the students are working on Part (d). Then comes discussion leading to some real uncertainty about one of their answers. Tracing back their logic, this discussion leads to the discovery of a wrong assumption in their answer on Part (a). This process involves intense and vigorous debate. Once the wrong assumption is identified, corrections are made and carried through to a final correct conclusion.

The presentation and analysis that follows is based on a transcript of the student dialogue, and examination of the written work they completed during the discussion.

*Notes relevant to clarifying technical point of the physics involved are shaded.*

*Contributions of the three students are identified with an A, B or C and annotations to the dialogue are printed in a right handed column.*

*Other commentary is interspersed.*

The written working recorded by Student B is reproduced below. The crossed out answers reflect the corrections made by the students after they reach Part (d) and discover an error in their working in Part (a).

(3 marks)

$$f_k = \mu_k N = \mu_k (400 \sin 25 - mg) = 1164 (0.27) =$$

a)  $f_k = \mu_k N = \mu_k mg = 0.27(136)(9.8) = 360 \text{ N}$

b)  $\cos 25^\circ = \frac{F_x}{400}$ ,  $F_x = 400 \cos 25^\circ = 362.5 \text{ N}$

$$a = \frac{F_x - f_k}{m} = 0.35 \text{ ms}^{-2}$$

c)  $v^2 = v_0^2 + 2as = 0^2 + 2(0.35)(5)$   
 $v = \sqrt{3.55} = 1.88 \text{ ms}^{-1}$

$$E_k = \frac{1}{2}mv^2 = \frac{1}{2}(136)(1.88)^2 = 241.1 \text{ J}$$

d)  $W = Fd = 400 \cos 25 \times 5 = 1813 \text{ J}$

e) Friction, noise, pushing snow away

#### 8.4 Getting Started: Working on Part (a)

It doesn't take the group long to settle. At no stage during the recording are any names used. The relationship between the students is based on their contact during the tutorials only. There is no indication of the group having explicitly discussed how they are going to approach the problem. They just start work on Part (a) with no preliminaries.

Initially the group made the assumption that the normal reaction force is the same as the weight (ie  $N=mg$  shown in the first crossed out line in their working). This arises after a brief discussion and is a consensus decision.

From the point of view of the physicist, this is not correct. The upwards effect of the lift of the huskies slightly reduces the normal force.

A OK  
Normal reaction on the surface.

Talking aloud. During the whole dialogue all three students work aloud. Sometimes this is communicating to others, but usually if it is a calculation it is talking to themselves.

A Sliding friction.  
By sliding friction they'll mean kinetic eh. ??

- |   |   |   |
|---|---|---|
| C | Normal reaction.<br>So you've got 136.  | Much is left unsaid. Steps<br>are often omitted.                                  |
| A | What's the mass of this sucker?<br>136.   |   |
| B | The normal reaction is the opposite. 1360   | The decision is made. No<br>account is taken of the<br>force from the dog sledge. |
| C | 1360  |   |
| B | Are we going to use 9.8 or 10? 9.8, unless it says to use<br>10.<br>Well we know all about that don't we? (laughter)<br>So (long pause) do we just draw it? | Here work commences in<br>earnest.  |

All three students are working on their own calculations, A and B on their own piece of paper, Student C only verbally. There is an active sharing of ideas about the process as well as answers. Student B is writing the group answer.

- A     It's really hard for simple questions for, like, everybody  
to get involved eh?

Significant comment is passed about the process of working on problems and what they are actually doing. This is sometimes called 'metacommunication'. There are several significant exchanges of this nature. Their discussion here is on the nature of group work with hard or easy problems.

- |   |   |   |
|---|---|---|
| B | It's real hard, for hard ones too, someone just fires off.<br>(laughter)  |   |
| A | Yeah, someone just <i>goes</i> . . eh? (more laughter).   |   |
| B | Someone who's wicked at physics.  | The implication being that<br>if a problem is really hard<br>then someone who is<br>'wicked' at physics just<br>takes off and leaves<br>everyone else behind. |
|   | (pause)   |   |
| A | OK, mg – upwards, Normal reaction.<br>Friction equals 9.8 times 136.<br>(Muttered section with a few numbers, unintelligible) | Back to work on the<br>problem.   |
| B | We don't have to account for this upwards friction do<br>we . . . (cut off)   |   |

- C 400 Newton's  
Yeah, that's the normal reaction force and you got normal reaction . . .
- Student C at this point seems to take on a dual role. He helps Student A and B working on the question, does his own calculations, but as we shall see is thinking about implications.
- B . . . (continuing) I mean with this 400 Newton's being an angle.
- C Oh for the first one we are just working out the normal.  
A We don't need that yet.
- Responding to B, simultaneously
- C Oh yeah.
- A Friction force - OK
- Back to working aloud.
- C Because the normal . . . is the exact opposite of whatever is pushing down. Isn't it ?
- Clear statement to the whole group.

This kind of statement occurs many times during the dialogue. It is a summary/clarification statement. These are usually addressed to the group. Sometimes there is a response, as in this case:

- B No the normal's not at the exact opposite, it's at right angles to where the surface is to the plane.
- Clear, definitive to the whole group.
- C But I wonder whether or not, because it's being lifted that lowers the normal.
- This is a critical comment. Student C returns to this theme several times.
- B So what do they want to know?  
Oh yeah, frictional force.  
The frictional force is the co-efficient of friction times its weight.
- C Yeah, that's 360.
- Helping again, while he seems to be thinking about his worry about the lifting.
- A Yeah, the normal force is just reaction off the surface. Any other force doesn't get included in the normal eh?
- This is addressed to the group. He is seeking a response and gets it from Student C.
- C I don't think so.
- C agreeing.
- B I just couldn't remember whether it detracted from the normal force eh. The co-efficient of friction is
- The use of the term 'detracted' is non-standard

subtracted from the normal force.

'street language'.  
Everyone knows what is  
meant.

A      Frictional force is about 360.

### **8.5 Starting on Part (b)**

The matter of the normal force is laid to rest for the moment and work continues on to part (b) of the question.

B      [Reading the question] "What is the acceleration of the  
sledge?"

C      Just the  $400 \cos 25$  isn't it?

Shorthand again.  
The question relates to  
acceleration, the answer  
given describes the force  
contributing to the  
acceleration.

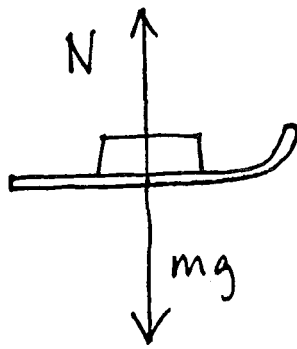
A      Yeah, horizontal component times  $\sin 25$ . No it's  $\cos$   
25.

There has been an enormous mental leap here. Steps in their thinking are left unspoken, and they have moved from the description of the situation to considering the forces involved. From there they go directly to considering the components of the force involved.

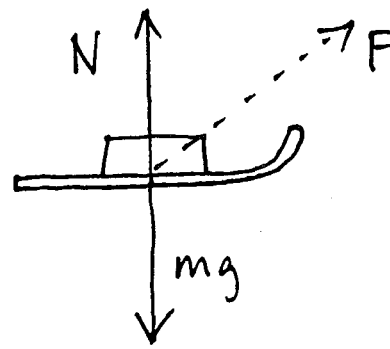
This is the first time there has been any mention of the word 'component'. They have made an error in their treatment of the normal, which comes from a failure to consider components. Yet in this brief interchange they are able to use the word accurately in context. We shall see later that they manage to sort out their error. But the question arises: Why do they consider the components correctly in the horizontal direction but not in the vertical?

A brief survey of problems in the student text shows that problems involving the normal force generally do not need consideration of components, since the vectors are all parallel to the normal force (Similar to Case 1 type problems below).





Case 1



Case 2

It is only when there is an extra pull force  $F$  as in Case 2 that components become vital. The size of the normal force  $N$  in Case 1 and Case 2 are not the same.

It is possible that none of the students had encountered a problem with exactly this context or a similar one where components are essential. For the students, this may have lead to an incorrect generalisation that “normal forces don’t involve components”. Leonard et al (1994) at the Scientific Reasoning Research Institute at the University of Massachusetts make this point:

Initial understanding of an idea is necessarily limited by the context in which it is first introduced. Ideas do not become globally useful until they are abstracted. The human mind seeks patterns and tends to generalise quickly and naturally using those features that are noticed. Students tend to notice superficial characteristics and often generalise incorrectly. Some students generalise based on only two examples and have difficulties re-evaluating and changing their generalisations when more examples are given. An old rule with many special cases is more easily created and handled than a new, more general rule. (p5)

Another possibility is that the understanding of the use of components is also context limited. Those contexts where they have used components in the past will tend to limit where they use components in the future. The component approach for these students may not yet be generalised as a method to be used *wherever* vectors are involved.

Whatever the source of this difficulty is, the students do eventually sort it out. This is an extremely important point: with no outside input of new information and relying only on the interaction arising from their shared understanding, the students develop in their understanding. It is unlikely that this would have occurred had these students been working on their own. The mental processes involved in the group interaction are essential for building new concepts.

A feature of the process is the constant monitoring of others and what they are doing. Small problems such as using different units are quickly resolved as they compare answers:

- C     I got a different answer.  
        I'll try it again.

B You're using degrees?

C I was in radians, sorry.

Calculation of the force proceeds:

C That's 2.5  
then we have to divide by the mass don't we.

There is often no mention of units.

B Yeah.

C So it's not going to be very fast at all?

C consistently makes comments on the sensibleness or otherwise of answers.

A  $F$  equals  $ma$  isn't it.

Abbreviated comment using formulae is common.

B Good thinking.

A We're just looking at, that's the force and direction.

B Therefore acceleration is force divided by mass.

B So if this thing actually stopped there probably wouldn't be enough force to get it going again eh?

Slightly muddled concepts and thinking here. Some active reflection on the values and implications of answers.

C Oh you mean because of friction.

B Um, yeah, it's so close.  
Yeah, look at that, it won't . .

A . . not when you've got an acceleration of 0.018.

C Yeah, static friction is probably more than that (laughter).

B . . .Divided by 136.

A Oh - that's no good.

A/B Equals 0.0189 – close enough.

A How could they actually measure that quick a speed?

The students are all involved, A and B formally on paper and, it appears, still muddling speed and acceleration in their words. Student C is doing calculations. All three are passing side comments at times, and also thinking aloud as they work.

### 8.6 Part (c)

Progress continues in this vein on Part (c). They decide after debate that '5m' means 'metres' not 'minutes'. There is a flurry of work as formulae are used to obtain answers. They discuss the role of kinematics in former physics classes. Again we observe rapid correcting of small errors in calculations.

- |   |   |   |
|---|---|---|
| A | Yes that's cool. - Yep - Yep - That's what I got as well.<br>What did you get? Oh wrong answer. Okay start again. |   |
| B | Yep I got that twice. 312.  |   |
| C | 435 I got.  |   |
| B | I think I might have forgotten to times something by 2.<br>There. That would make sense. (muttered calculations)  | There is a lot of thinking aloud.                       |
| C | You square rooted it.   | C is working but does not seem to be recording answers. |
| B | I screwed that up.  |   |
| B | 436.<br>Is that right?  |   |
| A | Oh - is it?   |   |
| C | Yes, something like that.   | Consensus is reached.<br>Time to move on.               |
| A | And what else did they want to know?  |   |
| B | Its kinetic energy.<br>Mass is - . . .  |   |
| A | 136 kg<br>times 0.439.  |   |

It should be emphasised that this written transcript leaves out a lot of the colour and flavour of the interaction. The issues change rapidly from debates about method, to details of calculations with regular comment on things like former physics classes and current tutorials. The students talk over one another. They interrupt and leave

sentences hanging. However, they are contributing to the group cause as well as 'thinking aloud' about their own calculations.

### 8.7 The First Doubts: An Answer for Part (c)

Then Students A and B reach an answer for Part (c) the kinetic energy. Student C however is not so sure:

B 12.9

A cool.

C No I think it looks a bit strange.

No reason is given.

A Work equals force times distance.

A is focused and working aloud on an answer to the next part.  
'Formula speak' again.

C It seems a bit strange. We are talking about a dog team. . . (interrupted).

C here is commenting on the value obtained for the kinetic energy in part (c).

It is not clear from the dialogue exactly what is significant about the dog team comment.

A (unsure) no . . . they're working together  
... 400 Newtons.

Responding to C's query.

C You know, this one's a bit strange. We are talking about a dog team. They are supposed to be working together.

C is persisting in his observations.

B Work equals force times distance.

B continues to work. More repetition and formula speak.

C Because there's friction, they're all supposed to be working together.

C continues with his analysis giving a little more detail. He is firmly persistent.

A In there . . . . No . . . . They're working . . . .

Vygotsky would probably refer to this as *dis-equilibrium*.

This last comment from A is incomplete, tentative and disjointed. A's thinking becoming unsettled. The dialogue continues with some intense debate often unintelligible in the recording, as at times all three students are talking at once. The debate centres around the effect of the 400N force in the forward direction and at the same time the lifting effect in the upwards direction.

## 8.8 Dis-equilibrium

The detail of the thought processes here are sometimes difficult to follow, with contradictions even in the space of three interchanges. From the perspective of an outside observer listening to a recording, some statements just don't make sense. However, the overall thrust is clear: to use Vygotsky's term, dis-equilibrium is setting in.

This is absolutely critical to the learning of these students. The students are starting to face the fact that they treated the force differently in Part (a) and Part (b). From the point of view of the physics involved, the components of the husky's pulling force should be used in both the forward and the upwards direction and added on to the other forces involved.

The debate begins with finding the work done. The question is: Which value should be taken as the *force* in their statement of the work equation,  $W=fd$ ?

- A      400 Newtons and then how far they've . . .
- C      But you pull the backwards force . . .      Worrying about friction.
- A      400 Newtons.
- C      No its force times it'd be that distance wouldn't it?      Seems to be pointing to a distance parallel to the 400N force.
- A      I don't know.  
Does it say horizontal work or just work?      This is a significant question.
- C      Because they are not actually lifting the sled that much.      This is a significant observation.
- A      Is it lifting the sledge? (*interrupting*)
- C      So I think it is just 360.
- A      not the 400.
- B      So they are lifting the sled quite a bit.  
I wonder how many wrong assumptions we've made about friction right at the start that's going to screw up all of our work.

This last statement marks a significant point in the dialogue. This worry about the sledge 'lifting' and the work involved has shed light on inconsistent thinking to do with forces, and the consideration of the normal force, in Part (a).

### 8.9 Seeing the Light

At this point, all three students realise there is a problem which they need to backtrack and examine. Would this have been picked up had the students been working on their own? I suspect not. Would they have 'learned' from this had they not been working in a group? Again I suspect not.

The dialogue continues with intense debate to resolve these issues. Statements are made and examined, then restated before discussion moves on. There is an examination of each assumption and how each fits with other assumptions. The central organising idea is the concept of work and how it relates to force and distance.

The students then discuss their dilemma:

A We'll have to scrap all of it.

C (unintelligible)

A What is the answer say?  
Was the problem ??

B Oh I don't know. I'm just wondering, you know.  
You screw up the first thing.

C I'm pretty sure we just count 360 with the 400 N.  
(clear positive statement).

A They are lifting the sledge quite a bit.

B Basically . . .

C No No, they're just pulling it like this.

Use of a calculator to model the sledge.

B No, they're actually pulling it like this.  
I wonder how many wrong assumptions we have made about friction right at the start.

B return to this theme of doubt and questioning.

Is the dog team lifting the sledge with the 400 Newtons?

Looking back to the assumptions in Part (a).

A How much force are the dogs providing on the sledge?

Discussion here centres on a drawing which was not handed in with their work.

C But it is still on the ground isn't it?

A Well . . .  
It's still on the ground, if you were something on the sledge.

The talk is getting increasingly animated.

- |   |  |   |
|---|--|---|
| A | But if it's still on the ground the forces must sum to zero, which means our assumption may be out. That our assumptions about friction was wrong.     | Examining the basic assumptions. A new concept is introduced here. Finally A sees the team's error. |
| C | There's no vertical distance. It's not moving.   | But C doesn't see the error.  |
| B | That's what I mean, there must be a bit of that force going in the vertical.   | Street language again, with the idea of components.   |
| A | Okay – we've got a vertical force here, we've got a vertical force down there, we've got the normal force.<br><br>( <i>unintelligible</i> )            |   |
| C | So if I do this, I'm not doing any work.   | More sounds of the calculator being moved around.   |
| A | Yes you are, you are pulling it up in the air. But it's still no work, because there is no distance.<br><br>( <i>unintelligible 3 voices at once</i> ) |   |
| A | We are talking about the assumption at the beginning with the normal force.<br><br>( <i>Unintelligible</i> )   |   |
| B | ... and they're doing it for a distance of 4m (or 5m). What's the problem.   |   |
| A | Yep, that's what I thought it was.   |   |
| B | It's getting ( <i>unintelligible</i> ) acceleration the sled and friction - it's the same.   |   |
| A | I don't think the question cares whether it is horizontal work or vertical work. I think it's just total work.   | This is a clear definitive statement to the whole group.  |
| B | Just 400 Newtons.  |   |
| C | It's just like if I pulled this almost upwards, like that and it moves that far. It's the same as if I pulled it there.                                |   |
| B | No it's not.   | Very softly and thoughtfully spoken.  |

C It's just that there is less tension.

Beginning to see that no (vertical) work does not mean that vertical components are irrelevant.

C is beginning to see that no (vertical) work does not mean that the components are irrelevant.

A Less tension, less work.

Thoughtfully.

A Less force . . . involved.

A You need to work hard to pull it along like that, than you do just pulling it straight.

B Yeah.

This is not wasted time. The external (vocalised) interaction reflects major change going on in the ideas and conceptual framework of each student. Without this interaction, it is unlikely that change would have occurred.

The transcript is quoted at length here to convey some sense of the debate. Again it is emphasised that this is a highly active and lively debate. Often three voices are speaking at once. However it *is* a three-way dialogue. The students are reflecting back ideas they hear and listening to the other points of view.

From the point of view of a physics instructor, this point – the forces and the direction of the distance - is relatively minor, and would take a few minutes out of a course of lectures. Yet for these students in their conceptual development, it is vital.

Their correct use of the components in Part (b) must now be seen in a different light: more of a half understanding, maybe even the mere use of an algorithm, rather than a true understanding of the concepts involved. Or alternatively, it is an approach that has yet to be generalised to the vertical, where there is no movement and applied to different contexts by the students. The group interaction has exposed the difficulties and furthermore, has helped correct some misconceptions and build in some new concepts.

With the use of their calculator as a 'model sledge', they continue the discussion of the lifting of the sledge:

B Assuming you did all the work getting it up there.  
(Pause)  
So in theory you don't ever use any more. But you do for that first initial stage of lifting it.

A It's a completely different thing though, the dogs aren't lifting. It's a completely different thing.



- C The distance is horizontal.
- A [Quoting from the question] "The dogs are exerting a force at 400 Newtons for a distance of 5 metres. How much work is done by the dog team?"  
(pause – silence)  
You might be right. I'm not sure.
- B You've got to get all your total work back then. So in theory you don't actually use any more but you do at that first initial stage of lifting which is... There is a lot of repetition here.
- C Hang on, what was the . . . (*cut off - unintelligible*) actual force I mean I think it was 400.
- A Here it's got the normal force helping it. Here you have to help it. You can still feel a strain on yourself.
- B Work is force times distance in there because it's being dragged down.
- B [Quoting question] "Dogs are exerting a force of 500 N".
- A Work by the dogs equals 400 times 5.
- C I'm pretty sure the distance is horizontal, so it's the horizontal distance the dogs are pulling you see?
- B No.
- C Cause otherwise you see I'm doing work.
- A You are doing work.
- A Ahh - but you did work to get it up to here.
- B It's a completely different thing though.
- B [Quoting] "The dogs are applying a force of 500 N for a distance of 5m. How much work is done by the dog team?"
- C You might be right, I'm not sure.
- A We'll do it like that then.
- B Well, if they have to pull it with the 400 Newtons force, we might as well give them credit for it. After going around in circles a little, Student B appeals to a new line of logic.

- A There's no magic genie there.
- B The whole thing is worth 3 marks like that's just like a giveaway.
- A [Quoting from the question] "Part (d) - Account for any difference".
- B What's worrying me is this first one to be honest, when we worked out N. The turning point.  
You've got some of the forces in the vertical, you've got that one right, you've got the weight force, and A focus on the heart of the issue..  
you've got the normal force.
- C Ahh, right yeah. A correct statement of the resolution.  
(a general chorus of agreement)  
Frictional force is less because there's less normal.  
You're right, we've got to go right back there.
- A Cause that's definitely providing an upwards force and the weight is providing a downwards force - you can't treat the normal the same as the weight, otherwise ... Another re-statement of the main point. Helping get this straight in his mind.
- B Ahh - you're right.
- C You're right.  
(Long silence)
- C Cause if you hold this almost off the ground there's less friction. Although C was last to see the release of components, he now seems to understand.
- B Um - you're right. It's like with the calculator, if you hold that like that, it's almost sloping, then it is easier to push if it's just like that. More re-statements.
- A That's for sure.
- B So what we were saying at the beginning about the normal being independent of friction . .

Then a final statement from Student A:

- A "Let's pick up a pen, shall we, and start again?"

It is a matter of a few minutes to correct all the working for the erroneous answers for Parts (a) – (c). The result of this can be seen in their answer sheet as reproduced early on in this chapter. Working is crossed out, and after recalculating, new answers written in. There is almost no talking or conversation during this time – just Student A reading out a few calculations, and Student B and C responding with numerical answers.

### **8.10 Conclusion: Has Real Learning taken Place?**

Evidence from this extract could be used to show a simple view of learning, where an old (incorrect) idea is merely replaced with a new (correct) idea. However this is a narrow and truncated view which omits consideration of many subtleties of the discourse.

From the point of view of the physicist, the same process must be applied to both Part (a) and Part (b). In each case to use technical terms “the force vectors need to be resolved into their components and then added.”

However, the students failed to do this for Part (a) while correctly doing it for Part (b). They have in their minds, for a while at least, two contradictory mental models. Within the same context of this one problem we see the students with two contradictory ideas held in close proximity to one another.

In the problem that the students worked on, there were two specific settings: firstly resolving vertically in Part (a), and then horizontally in Part (b). The students apply principles from a different mental model to each case. Later on in their dialogue the contradictions become clear.

How do we know what is going on inside the minds of the students? We can hear their talking, which sometimes is thinking aloud, not communicating to the others. There are pauses and muttered groans on the tape which can be inferred that struggle is taking place with ideas and their implications. From observing other groups, we can be certain that other outward signs would have been present: certain expressions, a head in hands and slouches for example, showing active struggle with problems. Signs of boredom or mental passivity, such as gazing fixedly round the room would not be in evidence. The recording sounded too active for this. At other times focussed writing would probably have been observable.

In Piaget’s terms, there is a challenge to the mental relationships the students have between ideas (their mental models) and what they observe and talk about in their interactions. The connections and relationships in their mental model were then seen as inconsistent. These inconsistencies were then faced and change took place.

What brought about this change? Discussion and interaction played a part (outward activity) as well as individual thinking (inner activity). We can hear the discussion as it unfolds. We can also get some sense of the inner (mental) activity as the students talk aloud. This talk is not to the group, but reflecting their thinking, helping clarify and cement it by their talking aloud. The changes and developments in their thinking are then reported to the group in speaking with a different purpose, in this case to communicate their new understanding with the others. This conversation with others is reflecting the inner speech as the learner works through the process facing the challenges to their mental models. The problem starts in the public arena of their discussion, goes internal to each student then re-emerges into the public arena.

What is the nature of the change that has taken place? We cannot automatically assume that real or permanent learning has taken place. There are a range of possibilities.

The first possibility is that *conceptual change has taken place*, in Piaget's terms, assimilation. The next possibility is *the addition of another fragment of a mental model* to what already exists. This is what Piaget calls accommodation. This could lead to the development of several schemas, each being used in a different context. A third option is the complete *replacement of the old schema with the new*.

I suggest the third option, replacement, is unlikely and that of the other two the first, real conceptual change, is the most probable. Two contexts, the horizontal and the vertical are seen now as just examples of a general case. One approach in one context, the vertical, has been dismissed as wrong and is discarded. The other approach for the horizontal is generalised. Key significant aspects are clear to the students, as we can see by the comments they make when working on the correct solution. The evidence suggests that real learning and real conceptual change has taken place and that this is not just by a complete replacement of the old but is part accommodation, largely assimilation. It is important also to note that the stimulus for this change came both externally from the group debate and interaction, and partly from individual internal mental activity. The group interaction was essential for learning in this example.

## 9. Essential Roles and Attitudes for Success

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### 9.1 Introduction

This chapter evaluates the various roles and working environments in the successful small groups. Success is taken to be satisfactory solutions to problems in the small group setting, where the problems were not trivial for the group members.

The roles we had described to the students in the tutorials were those of manager/leader, energiser, monitor/criticiser and recorder. Analysis of the sessions shows that in the groups that achieved success, certain roles or functions were always present, that of the critic or monitor. That is, there was in some sense a source of ongoing evaluation of what the group is working on, or in a more subtle sense, comment on how the group itself is functioning.

The other significant role was that of manager, leader or initiator. However groups could succeed with weak leadership, provided there was a positive collaborative focus on achieving the goal of the group.

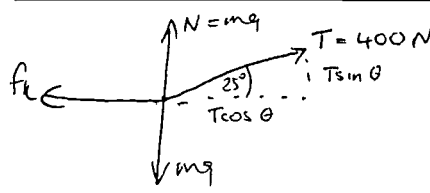
### 9.2 Essential Roles

All groups are self-selected and had full knowledge that they were being recorded. They could be assumed to be aware of the roles expected of their members. The successful groups seemed to be conscious of these roles during the recorded sessions, and commented accordingly – one individual going so far as to point out to his group that the researcher was interested in recording this kind of interaction.

#### 9.2.1 Session 1: A Well Functioning Group

The dialogue from Session 1 presented in the previous chapter is an example from a well functioning small group. All of the members made a contribution and there was a sense of them working towards the common goal. The role of *criticiser* was present. Opposing points of view were presented to the group, and the group responded well to these ideas. Knowledge was shared freely, and when needed, time was taken to talk through a difference of opinion. Debate involved checking out basic assumptions and testing them against each other's ideas as well as what was already decided.

This is in sharp contrast to the group in Recording 6. Their written answer is neat and clean, well set out and with almost no crossings out or scribbled notes. Parts (a) to (c) of the written work for Recording 6 is reproduced below:



a/  $N = \text{vertically} - \text{no net force} = N = mg$   
 $= (136)(9.8)$   
 $= 1332.8 \text{ N}$

$\Sigma F_x = T \cos \theta - f_k = ma = 0$   
 $T \cos \theta = f_k$   
 $= \mu_k N$   
 $= (0.27)(1332.8)$   
 $= 359.9 = ma$   
 $a = \frac{359.9}{136}$   
 $= 2.65 \text{ m/s}^2$

b/  $T \cos - f_k = ma$   
 $T \cos$

c/  $v_0, v, a, x$   
 $v^2 = v_0^2 + 2ax$   
 $v = 0 + (2 \cdot (2.65)(5 \text{ m}))^{1/2}$   
 $v = 5.15 \text{ m/s}$

$K = \frac{1}{2}mv^2$   
 $= \frac{1}{2}(136)(5.15 \text{ m/s}^2)$   
 $= 1802 \text{ J}$

In the answer to Part (a) the group makes the same wrong assumption as in the group in the Session 1 recording. However, no-one from the Session 6 group noticed this error and their interaction did not uncover it.

On listening to the recorded dialogue work proceeds very quickly and in a sequential fashion. Two students seem to do most of the work. There is no-one who takes on the role of monitor (who asks any questions about the operation of the group) or critic (examining critically the decisions of the group). The third member of the group is quieter. There is no way to be sure from the recording what his thinking is, whether he is completely lost or familiar with the work or somewhere in between.

I examined some written solutions from other groups where students finished a problem sheet quickly with a minimum of discussion. Some were very similar to the written work from the Session 6 group, with neat setting out, some indication that the group was familiar with the work, but with *wrong answers*. Sometimes there was evidence that those who were better students were working in an abbreviated fashion, trying to work in their head and missing out steps.

## 9.2.2 Session 5: The Monitor Function Assists a Leader

In recorded Session 5, there was a lot of debate and dialogue as one student tried to rush ahead but was forced to go back and re-examine his assumptions when questioned by others. He then discovered an error.

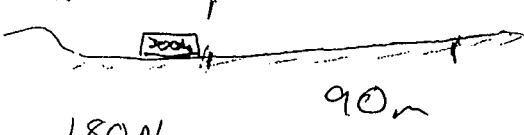
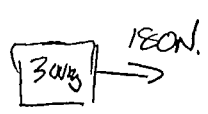
Their small group worked on a one dimensional version of the problem earlier in the course. The written working from Session 5 is shown here:

A reminder about the problem solving strategy:

- (1) Comprehend the problem.
- (2) Represent the problem in formal terms.
- (3) Plan a solution.
- (4) Execute the plan.
- (5) Interpret and evaluate the solution.

### Pushing a Sled

You are working on an exchange holiday on a Canadian tourist resort during a winter ski season. You are pushing a 300 kg loaded sled on an iced over lake. You manage to push it for 12 seconds with a constant force of 180N before you slip and watch the sled continue on in a straight line. How long will it be before the sled hits the shore some 90m away?

$t_i = 12s$      $d = 90m$      $V_f = V_i + at$   
  
 $180N.$      $90m$   
  
 $W = F \times d$   
 $= 180N \times$   
 $V_f^2 = V_i^2 + 2ad$   
 $V_f = V_i + at$   
 $= 0 + 0.6 \times 12$   
 $= 0.6 \times 12 =$   
 ~~$86.4 m/s$~~      $7.2 m/s$   
 $S = d/t$   
 $t = \frac{d}{S}$   
 $\frac{90}{7.2 m/s} = 12.5 \text{ seconds}$   
 ~~$10.8 \text{ seconds}$~~

Document 6

Even with the reminder of the problem strategy at the top of this sheet, there is little evidence of them using it. What they did do however, is to underline the key aspects of the question as they began the problem and started work. In effect they used their own version of the strategy. The scribbled alterations represent the changes due to the effect of the other student in the group seeking clarification and explanation of how the problem was being solved.

This bears out a finding in Heller et al (1992b, p634) where it is reported that in their analysis the lower or middle ability students sometimes provide the monitoring role in response to leadership and solution generating from more able students.

In Session 1 the role of *monitor* was sometimes shared around the group rather than resting with one individual, but did primarily rest with Student C. There were regular comments checking up on how things were going from all group members however, sometimes restating a decision in different terms, at other times trying to reformulate a problem in another way to see how to tackle it. In the Session 5 group the role of monitor was fulfilled in a different way with gentle requests for clarification that forced a re-examination of the solution to the problem.

### **9.2.3 Session 2: Success from a Homogeneous Group**

Recorded Session 2 showed another group working on the exam question problem with the huskies. The recording for this was less distinct and hence more difficult to analyse accurately. However some useful insights are uncovered.

From the general tone of the comments these students are of average ability. No one student emerges as dominant. All three students contribute, and the leadership function is either shared around or rests with one of the students (Student G) who was referring to the textbook for help. This extract shows their extensive use of the text and their focus on formulas:

- Student H: Ah, formula . .  
There is some interesting formulas here. [Flipping through text book]
- Student I: So what's involved in here, say that there . . .  
Everything else would be a constant . . .constant.
- Student G: Now this is a constant, and it can't change, and that can.  
That force – [shuffling of paper – probably a text book]  
But [indecipherable] has to be acceleration – [more shuffling of paper]
- Student I: hmn. . .  
Are you looking through the book trying to find a formula?
- Student H: We're looking.
- Student I: If you want to find the work done, it would be a lot less complicated up the top there, because the force comes straight out there.



- Student G: Oh hang on , I know what we've done wrong.  
Cause the huskies are pulling 400 Newtons, so the force when we go force times distance must be that force times 400 plus 25 times the distance,- or do you have to take the friction into account?
- Student I: Well, if you are asked, the friction would have to use it, or we could just leave it out.
- Student G: But the  $\mu$  [greek letter *mu* is used for coefficient of friction] is usually in that direction, not up that way.  
See if we you like use like  $v$  in that direction. Not up here.
- Student H: Hm. I don't know.
- Student I: Hang on. See if you use a  $v$  in that direction, up here. [pause – probably writing]  
Hm. So that doesn't really count then, does it?
- Student G: I don't know.

At this point, the group has really reached an impasse. There is no evidence of any clear correct understanding of the problem, so far. All the working is based on a wrong understanding of Part (a). There is a long pause. There are a few shuffles and some sighs.

There is the sound of the tutor talking to a group nearby. He didn't approach them and they did not seek help. It may be that because of the recording in process they thought they had to work without the tutor, and the tutor may have been more inclined to leave them alone for the same reason.

The quietness continues for several minutes. There is some more shuffling of paper. Then:

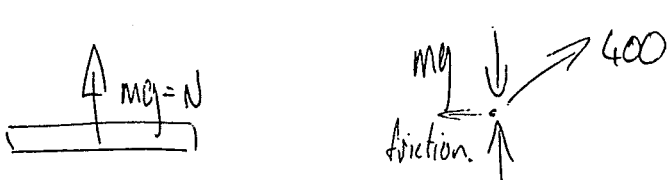
- |            |  |   |
|------------|--|---|
| Student H: | Work, I think. [Stated firmly] Why don't you use this one for work?    | Referring to a formula in the textbook.   |
| Student I: | We did.  |   |
| Student H: | Did you use $\cos \theta$ ?<br>[Pause]                                 | This is very significant. $\cos \theta$ refers to components. Up until now they have not used the components in the vertical direction.                                     |
| Student I: | Well, we didn't before when we were working out.<br>[Pause] Oh. I see. | This seems to be a side comment, possibly showing that G has been following her own line of logic in a search for a solution. Quietness does not necessarily mean inaction. |
| Student G: | The force is $ma$ , the distance.                                      |   |
| Student H: | Yeah we did that, but we've just seen this one here. $Fd \cos \theta$  | Telling G that she has a possible answer to the problem   |

Student I: I've got work equals  
[unintelligible]

The dialogue becomes indistinct at this stage. The outcome however is that the  $\cos \theta$  factor previously missing from their thinking is added in. Answers to Part (a) and Part (b) are corrected and the carry on with their errors fixed.

Here is a reproduction of their written work. Notice the two alternative (correct) answers to the (unlabelled) Part (a) and Part (b). For some reason they didn't bother to cross out the incorrect answers. It seems the working was carried out on another piece of paper and the answers copied in.

Written work from recorded Session 2:



Normal Reaction =  $1332.8 \text{ N}$  upwards  $\Rightarrow$   $1164 \text{ N}$   
 Frictional Force =  $0.27(1332.8)$   $\Rightarrow$   $314.2 \text{ N}$   
 $\quad \quad \quad = 360 \text{ N}$   
 Horizontal force =  $400 \cos 25$   
 $\quad \quad \quad = 362.5 - 360 = 34.2$   
 $\quad \quad \quad = 252 \text{ N } 48.5 \text{ N}$

$F = ma$   
 $a = \frac{F}{m} = \frac{48.5}{136} = \cancel{0.357} \text{ m.s}^{-2} \quad 0.36 \text{ m.s}^{-2}$

c)  $v^2 = u^2 + 2as$   
 $u^2 = 0$   
 $v^2 = 2as$   $\quad \quad \quad \cancel{v} = \frac{\cancel{v^2}}{2a} \quad v = \sqrt{2as}$   
 $s = \sqrt{\frac{1}{2} v^2 / a}$   $\quad \quad \quad v = \sqrt{2 \times 5 \times \cancel{0.357}} \quad 0.36$   
 $v = \cancel{4.36 \text{ m.s}^{-1}} \quad 1.89 \text{ m.s}^{-1}$

$E_k = \frac{1}{2} m v^2$   
 $\quad \quad \quad = \frac{1}{2} \times 136 \times \cancel{0.436^2} \quad 1.89^2$

This group has used their shared resources to make their way to a correct answer. They have referred extensively to the text. Part of the reason why they were able to reach a successful solution was due the positive interaction between them. There is active discussion of the various concepts involved. All students at times assumed the role of monitor or critic. Ideas were shared and put up for discussion and often rejected or accepted on the basis of what the textbook had to say. The discussion had less coherence when compared to the Session 1 group. But the role of monitor and critic was vital in the process.

This group struggled with some of the basic ideas. They finished with the comment from student G:

We've got the answer, but we can't explain it.

Even so, their answer was correct. They were working within the bounds of their zone of proximal development, but only just.

#### **9.2.4 Session 3: A Group of Two, Monitoring Still Needed**

This group ended up working as a two-some rather than a group of three. They also took with them their written work, something I had not intended. All I had to work from was the recording.

The question for this session was the same as for Session 5 (reproduced above). The work in this session is done almost exclusively by one of the two students with very little contribution by the other. Here is a small extract from Session 5, calling the two students N and H:

Student N: 300 kgs which is 0.6 metres per sec  
square – ahm – then that is easy enough  
now.

Now we use the  $v_f^2$  squared equals  $v_i^2$   
squared plus 2  $ad$  – enter.

Student N is pushing the  
<enter> button on the  
calculator. The  
conversation here is  
verbalising for the  
formula  $v_f^2 = v_i^2 + 2ad$ .

and when you times it - that

Student H: then we don't have distance

Student N: We don't have distance so we've got to  
re-write that for time.  
What one was it?

Student H: Plus the fact of acceleration.

Student N:  $V_f$  equals  $v_i$  plus  $a$  squared – sounds  
pretty good. We will try that.

Student H: If it is wrong it is N's fault.

Student N: At least I can remember a formula

.....initial zero plus acceleration 0.6  
times  $t^2$  squared which equals 144  
times .6 which is plus the number of the .  
. [unintelligible muttering]  
86.4 m per sec - which sounds awfully  
big .

I take the comment “If it’s wrong it’s N’s fault” to be addressed to me as the observer via the recording. Student H does not feel part of the process. I saw this kind of interaction in some of the early tutorials, where one member of a twosome tended to take over most of the work and the other became passive. At that stage it was decided among the tutors as a general principle to form groups of three.

This finding that groups of two did not seem to function as well is consistent with other research, for example Heller and Hollabaugh (1992) and Johnson et al (1998b). That research suggested that groups of four tended to lead to one member being left out. For these reasons and our experience also, the later PHYS102 tutorials were structured around groups of three.

Continuing with another extract from Session 3:

Student N: Here we are. So [calculating] .....so  
90 divided by 86.4  
which equals 1.4 secs .....

Student H: 1.04 seconds.

Either Student H is also  
calculating or is reading off  
the calculator – it’s unclear  
from the tape.

Their answer is 1.04, which  
they suspect is not correct.

There is a pause here, some discussion about the values obtained and a mutual decision that it is not reasonable. They refer to a textbook and there is flipping of pages. Then this, speaking as much to me as Student H I think:

Student N: Looking at our answer we have decided that for one person to accelerate  
that mass to 86.4 m per sec is extremely unreasonable  
So we had a look at a formula book and we discovered that the formula we  
used  $v_f$  equals  $v_i$  plus  $at$  squared was actually wrong  
It should be  $v_f$  equals  $v_i$  plus  $at$  in which case it works out at  
[tapping calculator . . .] 0.6 times 12 which means its final velocity all  
over is 2.2 m per sec.  
So 90 divided by 7.2 is 12.5 secs.  
Which sounds far more reasonable and is a good strategy [sic]....not a  
result that looks so wrong.

This reads more like a monologue. They evaluate their answers to see if they are sensible. This is enough of a monitoring activity to cause them to suspect an error somewhere, and to check their formulas. Again, the activity of monitor is critical to the success of the group.

### **9.3 Essential Attitudes**

Our observations suggest mutual commitment to the group goals is an essential ingredient for success. Once this is there, communication flows much more freely, and real progress in solving problems becomes possible. The interview data and other small group research tend to confirm this, for example, the extensive results reported in Johnson and Johnson (1993).

#### **9.3.1 Student-Student Communication “Second Teaching” and “Street Language”**

##### **Street Language.**

This term *street language* was introduced in discussion in Chapter Six. It refers to the use of colloquial hybrid language by the students mixing formal terminology with their own vocabulary and usage when discussing physics problems (Gatreau and Novemsky, 1997). In the Session 1 recording, student street language is present, with many physics terms being used with poor precision. Units are omitted or are wrong. Formulae are used as a conversational abbreviation to summarise clusters of ideas, yet the students would probably know of these inaccuracies if asked to clarify what they meant. What is important is that the communicated ideas are accurate, and that the hearer correctly gets the intention of the speaker.

The members of this group were communicating accurately. There are two ways we can judge this. Firstly, with only small technical adjustments to units and terminology, some of these interchanges involving all three students *do* make sense to an outside observer. Secondly, there are several times when clarification is sought. When messages are not getting through, the listeners seek further information. On all the other occasions, when they don't seek this clarification, giving other positive feedback instead, accurate communication is occurring.

Most importantly, throughout the whole process, concepts, ideas and conclusions were tied to well-founded shared understandings already in the group. The problem they were faced with was beyond the capacity of any individual member on their own, but within their shared capability. This ensures that real learning was able to take place, and is an excellent illustration of students working within their zone of proximal development.

Session 2, the other successful group on this problem made extensive use of quotes from the text in their discussion. They too took time to clarify uncertainties with each other and at times to challenge assumptions.

##### **Second Teaching.**

The term *second teaching* was also introduced during discussion in Chapter Six. It refers to the repetition of concepts which were generally covered in formal lectures by the instructor. The repetition generally occurs when students are working on problems that follow the formal instruction but the idea couched in the students own terms. Second teaching is beneficial to both the speaker and the hearer. Practice in this context

is probably essential for lasting learning (Gatreau and Novemsky, 1997). Informal observation led me to believe that second teaching frequently occurred in the small groups. However, with the exception of recorded Session 1 reported on extensively in Chapter Eight which had several extended episodes, there were only fragments in the other six recorded sessions.

Here is a brief extract from Session 2. It shows some discussion and debate over the direction and effect of the various forces involved.

- Student G:  $Mgd \cos\theta$  – I think that that's just talking about this here. [Reference to text books]
- Student H: Should there be  $ma$  plus  $mg$ ? [Asking if there is another force involved]
- Student G: No – oh no.
- Student I: Could it be  $mg$  times distance. That's what we did is it?
- Student G: Well, the  $mg$  must come in there because you can't get it without you having moved the whole object. Even though the friction force would be less toward  $ma$ .  
The  $mg$  has to come in with that equation 'cause where's the energy go?
- Student H: It's just like momentum isn't it?  
Isn't it?
- Student I: If we do work equals  $mg$  distance – okay.
- Student H: Yep.
- Student I: I'm pretty sure this way, we get 6664 joules.
- Student G: But I think that's more about lifting something. We're not actually lifting it, we're just moving it.
- Student H: Correct.
- Student I: Yes but if we move it against friction, I'm pretty sure that  $mg$  plus  $ma$  –
- Student G: But the weight isn't changing.
- Student I: It'll be like the pulling energy, wouldn't it? Like the pulley?
- Student G: I don't know. Unless we say like work done against friction.

This kind of debate was typical of several of the recorded sessions. There is an attempt being made to address the concepts in the problem. One student is using the textbook, which has the effect of anchoring some of the terms of the debate in physics vocabulary. The technical terms are sometimes used quite loosely (momentum, energy and friction for example), but the intent of the speaker is generally understandable.

Most of the recorded groups functioned well. There was one group where one member tended to take over for the first part of the time, at least until questioned by another member of the group (Session 5). Likewise, the group of two (Session 3) did not really function as a group. However other groups functioned well. The group in Session 1 went particularly well. Each individual was focused on the group goal, and there was

general restraint in pursuing personal agendas. This in general was a feature of well functioning groups.

However from the interviews we know that many of the unrecorded groups, during normal weekly tutorials, did not succeed as groups.

## 9.4 Summary

The recorded small group sessions discussed in this and the previous chapter represent a range of outcomes. This table summarises some of the main points of comparison:

Session No	Which Problem	No of Students	Use of FBD?	Correct Solution	Comments	Monitor Critic Role
1	Exam	3	N	Y	<ul style="list-style-type: none"> <li>Group seemed homogeneous, of average to above average ability</li> <li>Use of calculator as physical model</li> <li>Initial error in Part (a) eventually corrected</li> </ul>	All members contributed to monitor/critic role at times, but mainly one particular student.
2	Sledge	3	Y	Y	<ul style="list-style-type: none"> <li>The group seemed homogeneous, of average ability</li> <li>They made extensive use of text for help</li> <li>Progress was made after much struggle with use of clues from the text</li> <li>Initial problems with Part (a) eventually corrected</li> </ul>	Weak critic/monitor role
3	Exam	2	Y	Y	<ul style="list-style-type: none"> <li>The only group of two</li> <li>One student lead most of the work, little input by the other</li> <li>Evidence other student felt uninvolved</li> </ul>	Some critic/monitoring role from lead student
4	Exam	3	N	N	<ul style="list-style-type: none"> <li>No evidence of Free Body diagram.</li> <li>Wrong basic assumptions, not corrected.</li> </ul>	Little evidence of monitor/critic functions
5	Sledge	3	Y	Y	<ul style="list-style-type: none"> <li>One lead student dominates</li> <li>Incorrect work in lead student uncovered with gentle and persistent questioning by a second student.</li> </ul>	Strong role of critic by this second student
6	Exam	3	Y	N	<ul style="list-style-type: none"> <li>Full neat working</li> <li>Work progressed quickly, in sequential fashion</li> <li>Wrong initial assumption not corrected</li> <li>Seemed to be a high ability homogeneous group</li> </ul>	Little monitoring/critic functions evident
7	Exam	3	Y	N	<ul style="list-style-type: none"> <li>Extensive use of free body diagram</li> <li>Lots of talk about my role (as the person who would listen to the recording)</li> <li>Basic errors in part (a) not picked up.</li> </ul>	Moderate critic/monitor roles evident



Free body diagrams were used in some of the groups, but without any real focus as physics tool. There was little use at all of any problem solving strategy.

A significant factor in these sessions is the centrality of the monitor/critic role. It is present in all the successful groups. In the groups that functioned well there was also a subtle and unobtrusive leadership/management role present. These findings suggest that to focus on the role of monitor/critic could particularly help students to improve their group work.

## 10. Tutor Feedback and the Exam Results

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### 10.1 Introduction:

This chapter reports on some formal tutor feedback and some data from comparing examination results.

### 10.2 Feedback from the Tutors

There were five tutors involved in tutoring PHYS102 in 1998. Towards the end of that year, three of the tutors completed a brief questionnaire and two of these consented to being interviewed to further probe their responses. They were asked about what their view of the typical student was like, how they worked with the students, and for general comment on the success or otherwise of the small group methods. This proved to be an interesting exercise. Each tutor clearly had an explicit mental model of what a “typical student” was like – and various common “types”. Further work to probe the nature of these different mental models is likely to be fruitful in developing a better understanding of the role of tutors, and to better equip them for the work they are involved in.

These were an experienced group of tutors, all having carried out this role for several courses in previous years. They had spent considerable time together in classes as students, or in various activities associated with their previous tutoring. Possibly because of this background, there was a remarkable degree of similarity in their views on tutoring and how they described their own approach.

Lillian McDermott at the Washington University Physics Education Research Group (PERG) believes a large investment is required in tutor training. (McDermott, 1993a. Her description uses the term TA (Teaching Assistant) which is equivalent to the role of ‘tutor’.) She sees the tutors as having a significant and central role to play. The training focus at Washington University is towards a good conceptual understanding of the subject, which includes the nature of common misconceptions among students. Patricia Heller and her team at Minnesota State University also see tutor training as significant, although the focus at Minnesota is more on managing group work with the use of specific strategies (Heller and Hollabaugh, 1992a).

It was realized while planning the changes to the PHYS102 tutorials that the tutors would play a significant role in bringing about the changes. It soon became obvious however that we had underestimated the nature and magnitude of the change that we were seeking to bring about, and the tutor orientation as it was conducted in 1998 was inadequate. Prior to the start of the tutorials, I held a two-hour training session to discuss the focus on small group work with the five tutors for PHYS102 and one tutor involved in the separate halls of residence tutor groups. For the first three weekly tutors meetings we discussed further some of the key ideas to do with collaborative learning. Of the three questionnaires returned at the end of the year, none of them recalled more than a vague memory of this initial orientation meeting. The significant and central ideas for the changes we intended to make to past practice had never become central in

the minds of the tutors. The ideas included the use of the problem solving strategy, the centrality of small group work and the type of problems.

It was clear from all the feedback however, that the tutors did acknowledge the weakness of merely *telling* students how to do problems.

As mentioned earlier in this section, each tutor showed evidence of having a mental model of what a 'typical' student was like. I asked the question of the tutors "How do you make decisions about what to do or how to respond to a particular student or group?" I do not think they had consciously thought about these issues prior to our discussion. From this feedback, it emerged that there were at least two specific factors that featured to the thinking of each tutors that contributed significantly to their decision on what was needed to help a student or a group.

Firstly, they made a subjective judgment about the level of motivation of the student, whether in their opinion the student was putting in the effort, whether they were working hard and really 'trying'. This is an instinctive and intuitive decision made by considering eye contact, the type of communication of the student and their focus on the job at hand. One tutor commented that the job of the student seemed to be to do as little as possible to get the work done, and to get the tutor to do as much of it as possible.

Secondly, they made a judgment on the ability of the student. There is more objective evidence here, especially after the first homework assignments or tests have been marked. However even this is flawed data. Students do not always "do their best" in some assignments. One tutor described this as purely a matter of priorities. His description was of a student making a choice between "a 10% chemistry research project that counts [for the final course mark] and a physics assignment which doesn't count for any actual marks – what is the student going to do?" They report obvious cases of copying of assignments just to get them done. So in some respects the issue of motivation and achievement are clearly not independent variables.

In spite of our attempts to establish a collaborative group work environment, the feedback from the tutors indicated that they generally still would focus much more on the specific *problem* in question rather than helping assist groups to function. When discussing a problem with the students, the tutors would aspire to helping students move from where they were now to the next step, reformulating a problem another way, giving an example, giving an elaboration or overview. This is what the tutors *wanted* to do. But often what in fact does happen, by both their own admission and by comments from the students, it is that they end up simply giving a strong lead to the right answer for the particular problem in hand. They may end up telling the student what the student wants to know, which is often not what they *need* to know for best learning to take place.

Our conclusion from observations in this study and from the overseas experience suggests that many times in this component of the course either directing the group back to part of the problem solving strategy, or attending to weaknesses in the group dynamics, may have deeper and more lasting results. Firstly, this kind of response tends

to help the students to become more active in engaging with the problems. Secondly, the students gain insights in approaching problems that are useful in other wider contexts. A strong lead into how to solve something in a specific context will help a student solve a particular problem, but the student may not transfer this insight to another context. Demonstrating the use of a general strategy will often provide an approach that the student can use in other contexts. Our preliminary observation here is that average or below average students are also helped by this approach to groupwork, even if they do find it harder in the short term.

What tutors are being asked to do in the redesigned tutorials may be counter intuitive. Telling a student what to do when they are having difficulty is the first natural response. It is certainly very different from the way they were taught when the tutors themselves were studying undergraduate physics courses.

What is the best way to train tutors? How can the role of the tutors be developed to improve learning in tutorials? How sensitive is student learning and small group success to the activities of the tutor? What facets of the tutors own personal view of students affects their choice of activity in tutorials? There is opportunity for further study on these questions, but it is beyond the scope of this present investigation.

Re-reading the collection of student interviews and the questionnaires it seems that there are a number of problems and issues that may be able to be addressed by specific tutor intervention. Communication about the groups, the group processes and the purpose of the tutorials is vital. This is referred to as *metacommunication*.

The concept of metacommunication refers to shared, but usually unstated, taken-for-granted assumptions about the nature of communication itself. It is communication about communication. Gregory Bateson defined metacommunication as the level of communication where "the subject of discourse is the relationship between the speakers" (1972).

From a Web Page <http://www.lclark.edu/~soan370/toneofvoice.html>

Metacommunication can occur in a variety of ways. Ballantyne (1997) reports on the positive effects from students when presented with feedback from last year's courses and some detail in what lecturers were doing to respond to it. It is a small step to discussing matters relating to course design. Heller and Hollabaugh (1992a, p642) report on a strategy initially designed to help students understand the group process. Groups were given five minutes at the end of each activity to discuss how well they worked together. Observation showed that when students were given this opportunity to discuss their group's functioning, their attitude to group problem solving improved.

One of the main arguments against including this activity in tutorials is simply that it creates time pressure. On the other hand there is an argument that 'less is more' – that overall, student achievement is improved if the time is taken to build up student learning skills, and students can benefit later with an improved rate and depth of learning.

With all of the eleven PHYS102 students that were interviewed, there was a brief time of wide ranging semi-personal chat after the formal recording had stopped. Their responsiveness to this opportunity to talk about the tutorials was excellent. I believe

that such a discussion in tutorials with tutors at the start of courses could help bring about a positive change of culture among students, leading to small group dynamics and further benefits to student learning.

### ***10.3 The Role of the Tutor: Conclusions***

As far as the students' feedback was concerned, the PHYS102 tutors for 1998 did a good job. In all the interviews there were no negative comments at all regarding their role and activities in the tutorials. While no questions directly focused on the role of the tutors, unsolicited comments by students were positive about their content knowledge, the way they explained things and generally how they related to the students.

However there is potential to improve the tutor training to better focus their attention on the role of small groups in the learning process. Stronger guidelines on structuring small group activities for success have worked in overseas studies (Heller et al, 1992b). Strong prescribed guidelines did not work as well here with this particular group of students, but as referred to in Chapter Seven, the indications are that they could be introduced with a more collaborative process and would be well received, especially when supported by regular communication, evaluation and feedback on the group processes and goals of the tutorials.

Such training for tutors should also include some of the background rationale for the use of the problem sheets and the problem solving strategy. It is unrealistic to expect physics students working as tutors to have a good understanding of teaching and learning theory, even as it applies to students in physics. Such orientation would not be too difficult with the availability of well-presented and practical material in the field of physics education research.

### ***10.4 Exam Result Analysis***

The format of the final exam, the type of question and the level for each of the two years 1997 and 1998 are the same as much as was possible. So too were the Bursary Physics papers for the two years 1996 and 1997, which were the papers that most of the physics students involved actually sat.

All the relevant marks were on spreadsheets and so a simple comparison was done.

Firstly the mean and standard deviation of the Bursary marks for each year group of students were compared. This was to give some sort of baseline for comparison. Other statistics are included for interest in the two tables below.

Bursary results compared:

<b>Bursary Physics PHYS102 students1997</b>		<b>Bursary Physics PHYS102 Students 1998</b>	
Mean	58.1	Mean	58.1
Standard Error	0.471	Standard Error	0.518
Median	58	Median	58
Mode	61	Mode	55
Standard Deviation	7.8	Standard Deviation	9.1
Sample Variance	61.1	Sample Variance	83.0
Kurtosis	0.098	Kurtosis	2.438
Skewness	0.089	Skewness	-0.140
Range	43	Range	76
Minimum	36	Minimum	10
Maximum	79	Maximum	86
Sum	15971	Sum	17968
Count	275	Count	309

The difference in the bursary mark mean of these two student groups was less than 0.5%. Hence, using this as a crude measure, the groups of students were of similar size and of similar ability as measured *only* through their bursary marks.

The final exam grades were then compared for the two-year groups.

The Final PHYS102 examination results compared.

<b>PHYS102 Final Exam 1997</b>		<b>PHYS102 Final Exam 1998</b>	
Mean	43.0	Mean	47.3
Standard Error	0.758	Standard Error	0.935
Median	42.5	Median	47.5
Mode	43.5	Mode	45
Standard Deviation	14.3	Standard Deviation	17.9
Sample Variance	203.9	Sample Variance	321.7
Kurtosis	-0.036	Kurtosis	-0.223
Skewness	0.184	Skewness	0.063
Range	77.5	Range	89
Minimum	9	Minimum	3
Maximum	86.5	Maximum	92
Sum	15270	Sum	17404
Count	355	Count	368

The median final exam grade was 5% higher for 1998, with a larger spread (and from this a higher set of top marks and lower bottom marks).

The exam results for 1996 were not available in a form suitable for this kind of analysis.

I have not compared other components of the assessment because apart from the laboratory component, the other assessments were quite different for the two years. The 1997 course gave credit for tutorial attendance, weekly homework, and had no mid-term test. In 1998 no credit was given for tutorials attendance, but there was a mid-term test. There was some small component of the course grade given for tutorial related assessment. Probably because of this, tutorial attendance remained high in 1998 even with no formal course credit being given.

With this 5% increase in median mark from 1997 to 1998 in the final exam, the strong conclusion from this is that there *has* been an overall improvement in student achievement and that this is due to the only significant changed variable, the small group interaction in tutorials. However, for a true and valid comparison, the final examination for each year would need to be identical, a situation which is not possible.

## 11. Evaluation and Conclusions

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The primary purpose of this study was to investigate student learning in physics in collaborative small group tutorials. There is significant evidence from overseas studies that a collaborative learning approach is more effective than traditional tutor-centred approaches. Based on these overseas research findings, changes were implemented to the structure and content of PHYS102 tutorials at the University of Canterbury in 1998. A secondary purpose of this study was to evaluate the success of these changes. This study was then to consider how the tutorial component of PHYS102 might be further improved and what the collaborative learning approach has to offer other New Zealand courses.

Chapters Three and Four outline findings from key overseas research studies on small group work including Heller et al (1992b), Heller and Hollabaugh, (1992a) Gatreau and Novemsky (1997) Linder and Hillhouse (1996) and McDermott (1993a). Further theoretical work reported in Redish (1996a) and Mestre and Touger (1989) develops a model of learning specifically for physics. This model draws on collaborative learning theory as described in various studies by Johnson and Johnson (1998b, 1993a and 1993b) and which in turn draws on work by Piaget and Vygotsky.

This model for physics instruction states that not only is small group work effective, but further, it is *essential* for effective student learning. The work by Heller and Hollabaugh (1992b) suggests that it helps all levels of student from the average through to the able, and produces better solutions to problems than from students working alone. Their conclusion is supported by research into learning styles (Felder, 1995 and Redish, 1994). The argument is that while small group work has long been used in laboratory work to maximise the use of laboratory equipment, it should now be seen to have an essential place in both laboratory and tutorial work due to its effectiveness in assisting student learning.

In summary, the learning model involving collaborative small groups has a large research base, and an increasingly strong theoretical framework. (For a summary see Redish 1996a.) The results of this study in PHYS102, confirm here in this country, two well-established findings of collaborative learning research from overseas.

1. Collaborative small group work *can* improve the learning of physics students beyond the general level reachable by individual work.
2. For small groups to function well, they need to be well structured and managed. They do not just happen.

In well-functioning co-operative groups, students can interact, share ideas and methods, and seek clarification and justification from others (Gatreau and Novemsky 1996). This takes certain pressures off the tutor and puts them onto the students, requiring them to take a more active role in their learning. Better quality solutions to more difficult problems can result (Heller et al 1993b). Data from the present study suggests that this kind of collaboration did occur during PHYS102 tutorials. Observations and feedback



suggest that the constructivist model of learning in physics is sound, and has much to offer teachers to help develop and evaluate educational strategies.

It is with the findings of these overseas research projects in mind that changes were made to the PHYS102 tutorials in 1998. Chapter Four details the background to these changes. Previously students and tutors were used to a tutor-centred individualistic environment in tutorials. The culture among students and the physics background that students bring to introductory physics courses in this country is quite different to the overseas context. It is normal for students to arrive with much more physics background due to the different course structure at high school. Also, the style of education at high school level here in New Zealand has many differences. Hence there is a need to test these results in this country.

The data for this study included student interviews, tutor feedback and observations of small groups in action. Gathering of data had to be done carefully with due sensitivity to the fact that these students were studying in a real course where results counted.

The first major source of data was the students themselves. Eleven students were given a questionnaire and participated in follow-up interviews. The information emerging showed a picture of the intricate interaction between what students believed they should do and what was best for them, and what they said they did, which may in turn have been different to what they *actually* did.

Recording small groups at work on a problem was the second major source of data. These recordings captured a complex interaction as students worked together. They made extensive use of “street talk”, a half-breed terminology mixing physics jargon and students own ideas and words. This included unusual expressions that indicated an accurate and correct grasp of concepts as well as correct physics terms with indication of a poor grasp of basic ideas, as well as every other possible hybrid. The tutors also reported on their observations and experiences in the tutorials.

There were three major threads to the changes in PHYS102 which were not all equally successful. These were the new style of problems (‘context rich’ problem sheets), the problem solving strategy (an explicitly defined specific method) and the suggested ‘roles’ for group work. These three threads were designed to encourage a robust environment for collaborative work. The focus on groupwork represented a significant cultural change for students who were used to working almost exclusively on an individualistic basis. Collaborative work does occur in ‘projects’ and in the laboratory, but often only extending to the end of the data gathering stage, with further analysis then done individually; it is almost non-existent in activities involving problem solving. To assist a smooth transition to this new way of working together, a tutor orientation session was held to help train tutors and handout notes prepared for the students.

The ‘context rich’ problem sheets were well received by students, their feedback being positive and enthusiastic, describing these sheets as ‘interesting’, ‘fun’ and ‘helpful to their learning’.

The problem solving strategy was largely ignored by students. However, evidence in the results from the recorded small group sessions as presented in Chapters Six and Seven showed that the student groups as a whole continue to be desperately in need of the ideas encapsulated in the strategy. Students still tend to use a methodology based on a random search for a formula, with poor results. The students showed no sense of need for a better strategy, or even if they did, they tended to lapse back into old ways when actually working on problems. In reflecting on the process, one of the tutors suggested that a solution to this problem could be for tutors to develop and trial a suitable strategy *in collaboration* with their classes, rather than merely explaining a pre-designed format.

The third aspect of the changes was the specific group roles which were presented to the students during tutorials. Having these roles formalised in this way did not appear to have much influence on the actual behaviour of the students. Part of the process was to assign roles to group members when commencing work on a problem. Several students described problem solving sessions where they merely wrote down names of group members next to roles at random and then ignored the roles during the rest of the problem solving session.

Chapter Nine describes essential roles and attitudes for success in small group work based on the interviews and the recorded small group sessions. The group roles as formulated for the PHYS102 tutorials were ‘manager’, ‘recorder/checker’, ‘skeptic’ and ‘energiser/summariser’. Analysis of the recorded sessions showed that for consistent success, the function of *monitor* or *critic* must be present in some form in the group dynamic in a collaborative and supportive environment. Whether the role was formally assigned or spontaneously emergent as the group worked on a problem, it was clearly present in all the successful observed groups. Furthermore it was non-existent or barely discernable and superficial in the groups observed that did not succeed.

Another group role that was linked strongly with success was the function of leadership or management that was seen to emerge in a variety of ways such as *influence*, *suggesting options*, *co-ordination* or *taking the lead*, and need not be the same person for the duration of a session. It may well be the case that New Zealand students are reluctant to take the lead strongly and that groups do not encourage this anyway. In this respect the groups were much more collaborative than we initially expected them to be.

In the small group sessions, students were forced into new and often unfamiliar roles. They did not always find this pleasant, several students admitting that “most students prefer the easy path of having the answers given to them.” The question arises as to the extent of improved learning in physics that could be expected with more experience among students of working effectively in groups.

The interview data of Chapter Seven indicated that among some students at least, there was a reasonable level of understanding of how a well functioning group *should* operate. However there was wide variation among students in the ability to help make a group perform well and in the motivation to actually make an effort to do this. To help improve this situation, a more general and less prescriptive account of “Roles for Effective Groupwork” may better suit the kind of student in PHYS102. This could

usefully refer to findings from this study, and should focus on the role of monitor/critic, but as mentioned above with developing the problem solving strategy, a shared understanding of effective roles should be developed with input from the students.

The focus of this study was on the small group work rather than the role of the tutor. However, comments from the students interviewed clearly showed that the role of the tutors featured highly in their thinking. They showed clear ideas on what constituted 'good' or 'effective' tutoring. They wanted to be 'given the answers' or to have the problem 'explained'. With gentle probing during the interviews, it became clear that what is meant by some students by 'explaining' is being 'given a step by step method' which is usually very specific to the problem in hand.

As is described in Chapter Ten these ideas were quite divergent from the views of the tutors. The tutors indicated that during the interactions in the tutorials they tended to make on-the-spot judgements about students and what students need, based on two factors. The first factor is their subjective evaluation about the level of motivation of the student based on feedback such as eye contact, involvement or focus. This evaluation indicates to the tutor the student's level of effort. The second major factor is their perception of the ability of the student. This may be based on previous test scores, or on a subjective judgement, possibly based on previous contact, or simply the way they have asked for assistance. With experience tutors tried to become more general in their explanations, pointing students to broad principles they could use in other cases and encouraging them to make the connections to the specific question for themselves. The students in general wanted more definite, focussed and narrow answers.

As to the role of the tutor during the small group sessions, both the view of the students and the view of the tutors were divergent from the theoretical and pragmatic ideas underpinning the changes to PHYS102. As discussed in Chapter Four when describing the changes to PHYS102, it was planned that they should become much more of a facilitator in the small group environment. However, the tutors indicated that while they made some attempt to modify their approach to incorporate the group facilitator role, this was not done quite as wholeheartedly as it could have been. It was also planned that tutors should point students to a general strategy and encourage the development of expertise with it. However they described a tendency to lapse back into the way things had been structured in previous courses with the tutor being the source of answers. As described by the tutors and comments in the interviews, it is clear that students were able to put pressure on tutors to get what *they*, the students, wanted.

The attitude, modelling and talk of the tutors is vital in developing attitudes and motivation in the tutorials, but the current situation will not change without better training for the tutors. Merely telling them in tutor training sessions is not enough – clear presentation of the theoretical and practical underpinnings is also needed. Our tutor orientation in 1998 was inadequate in this regard.

One unanswered question is specifically how much these changes have affected student learning and concept development for the 1998 PHYS102 students. The 5% increase in the median examination result from 1997 to 1998 is certainly a change in the right

direction, but would only be a valid comparison if both examinations had been identical, a situation not practical or possible. The analysis of the recordings from the small group problem solving sessions showed evidence of real learning and concept development over even short student interactions. During frequent discussions and the process of explaining or justification in these sessions, students *appear* to be developing their understanding.

Another question of interest is the quantitative effect of collaborative group work on the problem solving skills of students in general and those of different ability groups in particular. With the recent development of finely focused assessment items, such evaluation should be possible. From consideration of the students interviewed and the general observational feedback, a tentative conclusion is that students of average or lower than average ability in particular benefit greatly from group work. It should also be noted that these students will probably need more support and help to be able to overcome some of the obstacles to being involved in small group activities which will bring benefit to them.

In general, the PHYS102 students of 1998 were happy with the groupwork in tutorials. Research does suggest that this attitude alone in the learner can help improve learning (Redish et al 1998). In PHYS102 the small group work represented about half an hour a week, and as such was appreciated by students who, in groups that functioned well, indicated that it provided variety, helped them see how others work and gave them a chance to flex their mental muscles. They described a real sense of satisfaction from solving problems that at first they had found beyond them.

As outlined in the analysis of student feedback in Chapters Six and Seven, the students interviewed acknowledged the benefit of working with others, they enjoyed the new types of problems, and had views on managing problems with poorly functioning groups. The most common problem expressed was with group members who “knew it all” or dominated the group. The second major problem was lack of involvement by members in the group. There were various perspectives on these issues among those interviewed. Some students expected tutors to solve problems in the groups, some took the initiative to try and help the group function and others voted with their feet, leaving a group or changing tutorials.

In spite of these problems with the groups, this study shows that small group work is a useful alternative to the traditional style of tutor-centred tutorials and that a component of formal small group work is essential in concept development. There is a need for tutors to develop different skills and alter their role significantly. Instead of only providing answers to student questions, or working through problems on a whiteboard, tutors should also monitor and facilitate the small group work, giving feedback and direction as required. In their work with the tutorial group as a whole, and in the small groups, they should explicitly model the use of an effective problem solving strategy. Many student difficulties can be quickly and effectively solved by others in the small groups, leaving tutors with more time to assist poorly functioning groups.

The preliminary findings in this study strongly indicate that if the PHYS102 students are indicative of the culture of New Zealand students in general, and there is no reason to believe they are not, then the most effective way to develop the student skills in groupwork is *not* to deliver these in a predetermined format. Instead, a shared understanding of groupwork and guidelines for working together should be developed *collaboratively* in the tutorials, with input from the tutors, possibly some other outside help and the students themselves.

Overall, the evidence from the study supports a view that a good basis of shared understandings of group work processes, and with regular, clear communication about the nature and purpose of small groups, it is possible to develop a genuinely collaborative environment. This needs to be supported by a carefully worked out policy on associated assessment and attendance. This will take time and effort on behalf of tutors, lecturers and course supervisors, but will significantly enhance student achievement and understanding.

## References

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- Ballantyne, C. (1997) Improving University Teaching: Giving feedback to students. In Pospisil, R. and Willcoxson, L. (Eds), *Learning Through Teaching*, p12-15. Proceedings of the 6th Annual Teaching Learning Forum, Murdoch University, February 1997. Perth: Murdoch University. <http://cleo.murdoch.edu.au/asu/pubs/tlf/tlf97/ballan12.html>.
- Bell, B. (1995) *Responses to 'Challenging NZ Science Education' by Michael R. Matthews*. University of Waikato 1995. B. Bell (Collator).
- Chirnside, A.D. (1998) Pupils Understanding of Critical Concepts. From EDUC644 (University of Canterbury) Research on Teaching Course 1998.
- Cobb, P. and Yackel, E. (1996) Constructivist, Emergent, and Sociocultural Perspectives in the Context of Developmental Research *Educational Psychologist* Vol 31 No 3/4 Summer and Fall pp 175-190.
- Dawson Chris, Lyndon Harry, Lloyd David, Harfield Gill (n.d about 1994) Conceptual Mediation: Theory and Practice for New and Experienced Chemistry Teachers Unlabelled conference paper.
- Dettrick, Dr Graham W, (1998) Constructivist Teaching Strategies Monash University <http://www.inform.umd.edu/UMS+state/UMD-projects/MCTP/Essays>
- Dillenbourg, P, Baker, M, Blaye, A, and O'Malley, C. (1996) The Evolution of Research on Collaborative Learning from *Learning in Humans and Machines* Spada & Reiman (Eds).
- Driver, R. Asoko, H. Leach, J. Mortimer, E. and Scott, P. (1994) Constructing Scientific Knowledge in the Classroom *Educational Researcher* Vol.23, No 7 October 1994 pp5-12.
- Felder, R.M, Felder, G.N.Felder, and Dietz,E.J. (1996) A Longitudinal Study of Engineering Student Performance and Retention. v.Comparisons with Traditionally-Taught Students *Journal of Engineering Education*, 84(4), pp469-480 (1998)
- Felder, Richard M. (1996) Matters of Style *ASEE Prism*, 6 (4), 18-23 (December 1996)
- Felder, Richard M. (1993) Reaching the Second Tier: Learning and Teaching Styles in College Science Education. *J.College Science Teaching*, 23(5), pp286-290 (1993).
- Galbraith, B. van Tassell, M.A. and Wells, G. (n.d.) Learning and Teaching in the Zone of Proximal Development *Developing Inquiring Communities in Education Project*, University of Toronto.
- Gautreau R, and Novemsky L. (1997) Concepts First – A Small Group Approach to Physics Learning. *Am.J.Phys* (65) 5 pp418-428 May.

- Glaserfeld, Ernst von (1998) Homage to Jean Piaget (1896-1980) 12 April 1998.  
<http://www.oikos.org/piagethom.htm>
- Glick, Joseph (1997) Prologue An Introductory essay to Vygotsky (1997).
- Hake R. (1998) Interactive-Engagement versus Traditional Methods. A six-thousand-student survey of mechanics test data for Introductory Physics Courses.*Am.J Phys* (66) pp64-74.
- Halloun, I.A. (1998) Interactive Model-Based Education: An Alternative to Outcomes-Based Education in Physics *South African Journal of Science* Vol.94 pp 1-14 July 1998.
- Halloun, I.A. and Hestenes D. (1985) The Initial Knowledge State of College Physics Students. *Am.J.Phys* (53) 11 pp1043-1055 November.
- Heller P, Foster T, and Heller K. (1997) Cooperative Group Problem Solving Laboratories for Introductory Classes University of Minnesota, Minneapolis. ICUPE proceedings 1997
- Heller, P, and Hollabaugh, M. (1992a) Teaching Problem Solving through Cooperative Grouping. Part 2: Designing problems and structuring groups. *Am.J.Phys* 60 (7) July pp637-644.
- Heller, P. Keith, R. and Anderson, S. (1992b) Teaching Problem Solving through Cooperative Grouping. Part 1: Group versus individual problem solving. *Am.J.Phys.* (60) 7 July pp627-636.
- Hestenes D. (1996) Modeling Methodology for Physics Teachers. *Proceedings of the International Conference on Undergraduate Physics Education*, College Park, August 1996.
- Hestenes David (1987) Toward a Modelling Theory of Physics Instruction *Am.J.Phys* 55 (5) May 1987.
- Hestenes, D, Wells M, and Swackhamer G. (1992). Force Concept Inventory. *The Physics Teacher*, Vol 30 pp141-158.
- Illman, Thos H. (1998) "Constructivism" and Cooperation between Scientists and Educators: A Reply to Crowther WWW 12 July 1998.
- Johnson D.W, Johnson R.T, and Smith K.A. (1998a) Cooperative Learning Returns to College *Change* July/Aug 1991.
- Johnson D.W., Johnson R.T., and Johnson-Holubec E.J. (1998b) *Learning Together and Alone.* Cooperative Learning Centre, Minneapolis.
- Johnson, D. and Johnson, R. (1993) What we know about Cooperative Learning at the College Level *Cooperative Learning* Spring 1993 pp17-18.
- Johnson, D.W, Johnson, R.T, and Holubec, E.J. (1993) *Circles of Learning: Cooperation in the Classroom (4th Ed)* Edina,M.N. Interaction Books.

- Johnson-Laird, P.N. (1989) Mental Models From *Foundations of Cognitive Science*, Posner, Ed A. Bradford Book MIT Press London (1989) pp469-499.
- John-Steiner, Vera, and Mahn, Holbrook (1996) Sociocultural Approaches to Learning and Development: A Vygotskian Framework *Educational Psychologist* Vol 31 No 3/4 Summer and Fall pp191-206. Lawrence Erlbaum Assoc. Inc.
- Larkin, Jill (1980) Cognition of Learning Physics *Am. J. Phys* 49(6) June 1981 pp534-541.
- Leonard, W.J, Gerace, W.J. Dufresne, R.J. and Mestre, J.P. (1994) Concept-Based Problem Solving in Physics University of Massachusetts.  
<http://www-perg.phast.umass.edu/papers/CBPSP/CBCSP.html>
- Leonard, W.J. (1998) A Constructivist view of Science Education University of Massachusetts Physics Education Research Group dated 3 December 1998 <http://www-perg.phast.umass.edu/UMPERG/OurPerspective/Constructivism.html>
- Linder and Hillhouse (1996) Teaching by Conceptual Exploration *The Physics Teacher* Vol 34 p332 September 1996.
- Longbottom, John E, and Butler, Philip H. (1998b) Why Teach Science? Setting Rational Goals for Science Education. Accepted for *Science Education* September 1998.
- Longbottom, John E., and Butler Philip H. (1998a) Destinations, Dilemmas, Paradigms and Progress: The Advancement of Science Education Submitted to *Science Education*.
- Matthews, M. (1994) *Challenging NZ Science Education*. Dunmore 1994.
- Mazur E. (1997) *Peer Instruction* Prentice-Hall, Englewood Cliffs, N.J.
- McDermott, L.C. (1993a) How We Teach and How Students Learn *Australian and New Zealand Physicist* Vol 30, July 1993. Paper delivered at NZIP conference in Auckland in 1992.
- McDermott, L.C. (1993b) Guest Comment: How We Teach and How Students Learn-a Mismatch? *Am.J. Phys.* 61 (4) April 1993 pp295-298.
- Mestre, Jose and Touger, Jerold (1989) Cognitive Research – What’s In It for Physics Teachers? *The Physics Teacher* September, 1989.
- Nuthall, G. (1996) Commentary: Of Learning and Language and Understanding the Complexity of the Classroom. *Educational Psychologist*, 31 (3/4), pp207-214.
- Nuthall, G. and Alton-Lee, A. (1994) How Pupils Learn. NZCER Set Two (1994).
- Piaget, J. (1970) Structuralism Basic Books, New York 1970.



- Redish, Edward F, Steinberg Richard N, and Saul Jeffery M (1998) Student Expectations in Introductory Physics *Am. J. Phys.* **66**, pp212-224 (1998)
- Redish, Edward F. (1994) The Implications of Cognitive Studies for Teaching Physics *Am.J.Phys* 62(6) pp796-803.
- Redish, Edward F. (1996a) New Models of Physics Instruction Based on Physics Education Research Proceedings of the *Deustchen Physikalischen Gesellschaft*, Jena Conference 1996.
- Redish, Edward F. (1996b) Discipline-based Education and Education Research. <http://www.physics.umd.edn/rgroups/ripe/papers/nas/nas.html>
- Redish. E.H., Saul J.M., and Steinberg R.N. (1998) Student Expectations in Introductory Physics *Am J.Phys* (66) pp212-224, 3 March.
- Reif and Larkin (1976) Teaching General Learning and Problem Solving Skills *Am. J Phys* Vol 44 March 1976.
- Samiullah, M. (1995) The Effect of in-class Student-Student Interaction on the Learning of Physics in a College Physics Course *Am.J.Phys.* 63(10) October pp944-950.
- Sciamanda, Robert J. (1996) A Prelude to the Study of Physics. *Quantum* Vol 7 No 2 p45, Nov/Dec 1996.
- SECME Background Paper (1997) Cooperative Learning SECME Summer Institute 1997.
- Smagorinsky, Peter (1995) The Social Construction of Data: Methodological Problems of Investigating Learning in the Zone of Proximal Development <http://psych.hanover.edu/vygotsky/smagor.htm>
- Sokoloff, R. and Thornton, D. (1997) Using Interactive Lecture Demonstrations to Create an Active Learning Environment. *The Physics Teacher* Vol. 35 Sept 1997 p340.
- Strommen, Eric F. (1992) Constructivism, Technology, and the Future of Classroom Learning <http://www.ilt.colombia.edu/k12/livetext/docs/construct.html>.
- Trowbridge D.E., and McDermott L.C. (1981) Investigation of Student Understanding of the Concept of Acceleration in One Dimension. *Am.J.Phys* (49) 3 pp242-253 March.
- Van Heuvelen, A. (1991) Learning to Think Like a Physicist: A Review of Research-Based Instructional Strategies. *Am.J.Phys.* 59(10) October pp891-897.
- Vygotsky, L.S. (1978) *Mind in Society* Harvard University Press 1978.
- Vygotsky, L.S. (1986) The Genesis of Higher Mental Functions In J. V. Wertsch (Ed) *The Concept of Activity in Soviet Psychology* Armonk, N.Y. Sharpe 1986.

- Vygotsky, L.S. (1987) Thinking and Speech *The Collected Works of L.S.Vygotsky, Vol.1: Problems of General Psychology*. (Trans N. Minick, Eds R.W Reiber, and A.S Carton) N.Y. Plenum 1987.
- Vygotsky, L.S. (1997) *The Collected Works of L.S.Vygotsky, Vol.1: Problems of General Psychology*. (Trans Marie J. Hall, Ed Robert W. Rieber) N.Y. Plenum.
- Wells M, Hestenes D, & Swackhamer G. (1995) A Modelling Method for High School Physics Instruction *Am.J.Phys* 63(7) pp606-619.
- Wells, Gordon (1994) Learning and Teaching "Scientific Concepts": Vygotsky's Ideas Revisited <http://www.oise.utoronto.ca/~gwells/scient.concepts.txt>
- Wells, Gordon (1996) The Zone of Proximal Development and its Implications for Learning and Teaching <http://www.oise.utoronto.ca/~gwells/zpd.discussion.txt>
- Wells, Gordon (1996b) Text, Talk and Inquiry: Schooling as Semiotic Apprenticeship - <http://www.oise.utoronto.ca/~gwells/semiotic-apparent.txt>
- Welzel Manuela, and v.Aufschnaiter S. (1997) Investigations of Individual Learning Processes – A Research Programme with its Theoretical Framework and Research Design <http://www.physik.uni-bremen.de/physicseducation>

# Appendices

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## *APPENDIX ONE: Student Information for PHYS102 Tutorials*

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PHYS102 - 1998

### **Tutorial Information**

### **PHYS102: Dynamics, Waves and Atoms**

#### **General Notes**

- Tutorials are an important part of this course. This time is important for active engagement with the ideas presented in this course. Work in tutorials will emphasise a problem solving approach. Often work will be in small groups where students work together on a problems.
- Problems Solving. A formal five step method will be presented. This may seem a little formal and rigid to start with, but persistence will pay off. The type of problem may be a little different to the formula based problems some students are used to. Clearly developed planning steps will be required. Problems solving in small groups will vary from quite formal (with assigned roles) to informal and ad hoc groups. We will seek feedback regularly on how students are finding this activity.
- The Tutorial Assignment homework questions (see separate handout) will be due on the dates given and are to be handed in at the tutorials. These will be returned with answers. Part or all of these will be marked, focusing on different skills or topics each week. There will also be several quizzes and cooperative problem sheets completed during tutorials which count towards your course grade.
- The group work on problem sheets is important. Students can often achieve much more in a well-structured group than they can individually. This is an important part of the learning process. We also encourage students to work and study together out of class.
- Answers to problems. Answers may be emailed to students or made available on the Web or simply returned to students with their marked work. The electronic format for email or web material has yet to be decided, possibly JPG format, depending on whether we can get the size of the files down sufficiently.
- There is also a list of suggested problems. It is strongly suggested that you work on these in your own time, especially where you have difficulty, or where the problems particularly interest you.
- Assessment. 10% of the course grade will be assigned from work associated with tutorials. This will be made up of four formal assignments, four cooperative problem sheet exercises (completed in tutorial time) and four quizzes (also completed in tutorial time.) These will not occur in the first three weeks of the course. Fuller details will be available in week two.
- Tutors: Contacting your tutors outside tutorials. Each tutor will have a formal time when they are available as 'office hours'. They will give you details of this.

## **APPENDIX TWO: PHYS102 Student Handout on small group roles.**

### **Group Roles**

In your tutorials, you will be working in **cooperative groups** to solve problems. The ability to work in groups is a highly valued skill among employers. Group work has also been shown to be effective in student learning.

To help you learn the material and work together effectively, each group member will sometimes be assigned a specific *role*. You may not always feel totally at home in a particular role. This is quite normal, but experience has shown that working in different roles is helpful in developing good group work and collaborative skills.

There are many possible roles, but four we have chosen are:  
Manager, recorder/checker, sceptic and energiser/summariser.

### **The responsibility of each role**

The responsibilities for each role are defined on the chart below.

<b>ROLE</b>	<b>WHAT IT SOUNDS LIKE</b>
<b>Manager</b> <ul style="list-style-type: none"><li>• Direct the sequence of steps.</li><li>• Keep your group "on-track."</li><li>• Make sure everyone in your group participates.</li><li>• Watch the time spent on each step.</li></ul>	"Let's come back to this later if we have time." "We need to move on to the next step." "Chris, what do you think about this idea?"
<b>Recorder/checker</b> <ul style="list-style-type: none"><li>• Act as a scribe for your group.</li><li>• Check for understanding of all members.</li><li>• Make sure all members of your group agree on plans and actions.</li><li>• Make sure names are on group products.</li></ul>	"Do we all understand this diagram?" "Are we in agreement on this?"
<b>Skeptic</b> <ul style="list-style-type: none"><li>• Help your group avoid coming to agreement too quickly.</li><li>• Make sure all possibilities are explored.</li><li>• Suggest alternative ideas.</li></ul>	"What other possibilities are there?" "Let's try to look at this another way." "I'm not sure we're on the right track."
<b>Energiser/summariser</b> <ul style="list-style-type: none"><li>• Energise your group when motivation is low by:<ul style="list-style-type: none"><li>• By suggesting a new idea;</li><li>• Through humour; or</li><li>• Being enthusiastic.</li></ul></li><li>• Summarise (restate) your group's discussion and conclusions.</li></ul>	"We can do this!" "That's a great idea!" "So here's what we've decided"

## **A Problem Solving Strategy**

### **Introduction**

At one level, problem solving is just that, solving problems. Presented with a problem you try to solve it. If you have seen the problem before and you already know its solution, you can solve the problem by recall. Solving physics problems is not very different from solving any kind of problem. In your personal and professional life, however, you will encounter new and complex problems.

The skillful problem solver is able to invent good solutions for these new problem situations. But how does the skillful problem solver create a solution to a new problem? And how do you learn to be a more skillful problem solver?

Research in the nature of problem solving has been done in a variety of disciplines such as physics, medical diagnosis, engineering, project design and computer programming. There are many similarities in the way experts in these disciplines solve problems. The most important result is that experts follow *a general strategy* for solving all complex problems. If you practice and learn this general strategy you will improve your chances of success in this course. In addition, you will become familiar with a general strategy for solving problems that will be useful in the future.

### **The steps of a Problem-Solving Strategy**

Experts solve real problems in several steps. *Getting started* is the most difficult step. In the first and most important step, you must accurately *visualise the situation, identify the actual problem, and comprehend the problem*. At first you must deal with both the qualitative and quantitative aspects of the problem. You must interpret the problem in light of your own knowledge and experience; *ie. Understanding*. This enables you to decide what information is important, what information can be ignored, and what additional information may be needed, even though it was not explicitly provided. In this step it is also important to draw a picture of the problem situation. A picture is worth a thousand words if, of course, it is the right picture.

In the second step, you must *represent the problem* in terms of formal concepts and principles, whether these are concepts of architectural design, concepts of medicine, or concepts of physics. These formal concepts and principles enable you to simplify a complex problem to its essential parts, making the search for a solution easier.

Third, you must use your representation of the problem to *plan a solution*. Planning results in an outline of the logical steps required to obtain a solution. In many cases the logical steps are conveniently expressed as mathematics.

Fourthly, you must determine a solution by actually *executing* the logical steps outlined in your plan.

Finally, you must *evaluate* how well the solution resolves the original problem.

The general strategy can be summarised in terms of five steps:

- (1) Comprehend the problem.
- (2) Represent the problem in formal terms.
- (3) Plan a solution.
- (4) Execute the plan.
- (5) Interpret and evaluate the solution.

The strategy begins with the qualitative aspects of a problem and progresses toward the quantitative aspects of a problem. Each step uses information gathered in the previous step to translate the problem into more quantitative terms. These steps should make sense to you. You have probably used a similar strategy when you have solved problems before.

### **A Physics-Specific Strategy**

Each profession has its own specialised knowledge and patterns of thought. The knowledge and thought processes that you use in each of the steps will depend on the discipline in which you operate. Taking into account the specific nature of physics, we choose to label and interpret the five steps of the general problem solving strategy as follows:

#### **Focus the Problem:**

In this step you develop a qualitative description of the problem. First, visualise the events described in the problem using a sketch. Write down a simple statement of what you want to find out. Write down the physics ideas which might be useful in the problem and describe the approach you will use.

#### **Describe the Physics:**

In this step you use your qualitative understanding of the problem to prepare for the quantitative solution. First, simplify the problem situation by describing it with a diagram in terms of simple physical objects and essential physical quantities. Restate what you want to find by naming specific mathematical variables. Using the physics ideas assembled in step 1, write down equations which specify how these physical quantities are related according to the principles of physics or mathematics.

#### **Plan the Solution:**

In this step you translate the physics description into a set of equations which represent the problem mathematically by using the equations assembled in step 2. Write down an outline of how you will solve these equations to see if they will yield a solution, before you go through the effort of actually doing any mathematics.

#### **Execute the Plan:**

In this step you actually execute the solution you have planned. Combine the equations as planned to first determine an algebraic solution. Then plug in all of the known quantities into the algebraic solution to determine a numerical value for the desired unknown (target) quantity. At this stage you may be able to carry out a rough calculation to get an idea of the order of magnitude of the answer.

### **Evaluate the Answer:**

Finally, check your work to see that it is properly stated, reasonable, and that you have actually answered the question asked. Remember the units. Check: is your answer sensible? Is it the right order of magnitude?

Consider each step as a translation of the previous step into a slightly different language. You begin with the full complexity of real objects interacting in the real world and through a series of steps arrive at a simple and precise mathematical expression.

The five-step strategy represents an effective way to organise your thinking to produce a solution based on your best understanding of physics. The quality of the solution depends on the knowledge that you use in obtaining the solution.

Your use of the strategy also makes it easier to look back through your solution to check for incorrect knowledge and assumptions. That makes it an important tool for learning physics. **If you learn to use the strategy effectively, you will find it a valuable tool to use for solving new and complex problems.** After all, those are the ones that you will face in any future work in the 'real world'.

## **APPENDIX FOUR: The Student Questionnaire**

Note: Section B was included in the questionnaire, but not in the formal analysis due to the small size of the actual sample. It is included here for the sake of completeness.

### **The Evaluation of PHYS102 Tutorials 1998**

#### **Questionnaire**

*Note: You are invited to participate in this evaluation by completing the following questionnaire. This will be followed by a brief interview based on some of the comments in the interview. Omit any questions you wish to.*

*The aim of the project is to gather data on student attitudes towards the tutorials and their effectiveness or otherwise. The results of the questionnaire and the interview will be anonymous in the sense that you will not be identified individually without your consent. By completing the questionnaire however it will be understood that you have consented to participate in this evaluation and that you consent to publication of the results of this evaluation with the understanding that anonymity will be preserved.*

#### **Section A**

**INFORMATION:** For the first part of the course the tutorials were set up in such a way that for part of each tutorial work was carried out in small groups on a single problem. It was expected that students should follow the guidelines of the problem solving strategy.

7. How useful did you find the problem solving strategy?

#### **The problem sheets**

8. Consider the Tarzan and Jane problem or the Lone Ranger Problems or the Aircraft Takeoff problems:

DO NOT DO THESE PROBLEMS NOW.

#### **The Lone Ranger and Tonto: Problem 2**

Instructions: On the sheet provided, work on this problem using the full problem solving strategy steps from Tutorial 1.

Tired at working for McDonalds you take on a job as a technical consultant for an early-morning cartoon series for children to make sure that the science is correct. In the script, a wagon containing two boxes of gold (total mass of 150 kg) has been cut loose from the horses by an outlaw. The wagon starts from rest 50 meters up a hill with a  $6^\circ$  slope. The outlaw plans to have the wagon roll down the hill and across the level ground and then crash into a canyon where his confederates wait. But in a tree 40 meters from the edge of the canyon wait the Lone Ranger (mass 80 kg) and Tonto (mass 70 kg). They drop vertically into the wagon as it passes beneath them. The script states that it takes the Lone Ranger and Tonto 5 seconds to grab the gold and jump out of the wagon, but is this correct? You assume that the wagon rolls with negligible friction.



## **Tarzan and Jane**

Instructions: As above. This problem is similar but different to the one above.

Because of your concern that incorrect science is being taught to children when they watch cartoons on TV, you have joined a committee which is reviewing a new cartoon version of Tarzan. In this episode, Tarzan is on the ground in front of a herd of stampeding elephants. Just in time Jane, who is up in a tall tree, sees him. She grabs a convenient vine and swings towards Tarzan, who has twice her mass, to save him. Luckily, the lowest point of her swing is just where Tarzan is standing. When she reaches him, he grabs her and the vine. They both continue to swing to safety over the elephants up to a height which looks to be about  $1/2$  that of Jane's original position. To decide if you going to approve this cartoon, calculate the maximum height Tarzan and Jane can swing as a fraction of her initial height.

Extra: Do on your own. How much does the tension in the vine increase in from before Jane picks up Tarzan until afterwards?

For this problem, hand in a clearly named group answer showing evidence of all the steps outlined in last week's tutorial handout.

## **Catapult assisted takeoffs.**

You have been asked to assist in a design project for a new catapult which will be used to launch a Navy jet from an aircraft carrier. The catapult is 100 m long and the aircraft is 23 tonnes. For takeoff the aircraft requires a minimum speed of  $90 \text{ ms}^{-1}$  and can provide a maximum thrust of 96 kN. Initial tests show the catapult can provide about 800 kN. Make a recommendation: is this enough force to launch the jet?

**In these problem sessions, comment on:**

How well the group worked

How much you felt you learned

How successful you felt you were

How did you find the type of problems set in tutorials?

How have they aided your learning?

How have they hindered your learning?

**Small Group Work**

What do you think are the pros and cons of working together in a small group?

What factors make a small group actually work well?

**Tutorials**

What do you think is the main function of tutorials?

## Section B.

Read each of these statements and rate each one on a 1 – 5 scale as indicated.

1: Strongly Disagree	2: Disagree	3: Neutral	4: Agree	5: Strongly Agree	
<ul style="list-style-type: none"><li>• Answer the questions by circling the number that best expresses your feeling. Work quickly. Don't over-elaborate the meaning of each statement.</li><li>• They are meant to be taken as <i>straightforward and simple</i>. If you don't understand a statement, leave it blank.</li><li>• If you understand, but have no strong opinion, circle 3.</li><li>• If an item combines two statements and you disagree with either one, choose 1 or 2.</li></ul>					
15. All I need to do to understand most of the basic ideas in this course is just to read the text, work most of the problems and/or to pay close attention to the lectures.	1	2	3	4	5
16. I go over my class notes carefully to prepare for tests in this course.	1	2	3	4	5
17. Problem solving in Physics basically means matching problems with facts or equations and then substituting the values to get a number.	1	2	3	4	5
18. Learning Physics has made me change some of my ideas about how the physical world works.	1	2	3	4	5
19. I read the text in detail and work through many of the examples given there.	1	2	3	4	5
20. In this course I do not expect to understand equations in an intuitive sense, they just have to be taken as given.	1	2	3	4	5
21. Learning Physics is a matter of acquiring knowledge that is specifically located in the material given in class and/or in the text book.	1	2	3	4	5
22. Only a few specially qualified people are capable of really understanding Physics.	1	2	3	4	5
23. The most important thing in solving a Physics problem is finding the right equation to use.	1	2	3	4	5
24. If I don't remember a particular equation needed for a problem in an exam there is nothing much I can do legally, to come up with it.	1	2	3	4	5
25. The main skill I get out of this course is learning to solve Physics problems.	1	2	3	4	5
26. Learning Physics helps me understand situations in my every day life.	1	2	3	4	5
27. A problem in this course is being able to memorise all the information I need to know.	1	2	3	4	5
28. Learning Physics requires that I substantially re-think, re-structure and re-organise the information that is given out in class and/or in the text.	1	2	3	4	5

**RELATED ISSUES:**

Studying for Tests

What activities do you engage in to prepare for tests?

Problem Solving

What sorts of approaches do you use to solve problems?

Your Results

What do you think largely affects your grades in this course?

How relevant is your past experience of the world to this course?

To understand Physics how much do you think about your personal experience in the topics being presented?

What do you think is the main skill you have got out of this course?

**Homework Problems**

9. Homework problems were also set. How many of these sets of problems did you complete?

10. How did you find these problems?

11. How useful were these problems to aid your learning?

12. Answers to the problem sheets were available in the Library.  
Was this enough?  
Would you be interested in answers being on the Web?

## **APPENDIX FIVE: Questions for the Recorded Small Group Sessions**

### **The Sledge Question.**

This question was used by Session 2 and Session 5

A reminder about the problem solving strategy:

- (1) Comprehend the problem.
- (2) Represent the problem in formal terms.
- (3) Plan a solution.
- (4) Execute the plan.
- (5) Interpret and evaluate the solution.

### **Pushing a Sled**

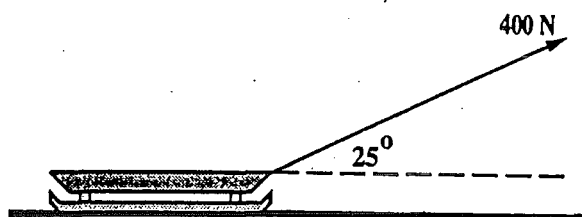
You are working on an exchange holiday on a Canadian tourist resort during a winter ski season. You are pushing a 300 kg loaded sled on an iced over lake. You manage to push it for 12 seconds with a constant force of 180N before you slip and watch the sled continue on in a straight line. How long will it be before the sled hits the shore some 90m away?

### **The Exam Question**

This question was used by Sessions 1, 3, 4, 6 and 7.

It was reproduced from the final examination for 1997.

2. A husky dog team in the Antarctic is pulling with a force of 400 N a supply sledge of total mass 136 kg. The pulling rope maintains an angle of  $25^\circ$  to the horizontal and the coefficient of sliding friction between the sledge and snow surface is 0.27.



- (a) What is the normal reaction of the surface on the sledge and the frictional force acting on the sledge? (4 marks)
- (b) What then is the acceleration of the sledge? (4 marks)
- (c) If the sledge starts from rest, what will be its speed after being pulled for 5 m? What then is the kinetic energy of the sledge? (3 marks)
- (d) How much work is done by the dog team in moving the sledge 5 m? (3 marks)
- (e) Compare the values of the work done by the dog team (part (d)) with the kinetic energy of the sledge (part (c)); account for any difference. (3 marks)